GARNET: ITS MINING, MILLING, AND UTILIZATION

BY

W. M. MYERS
and
C. O. ANDERSON

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**II.** Flow sheet of the Barton Mines Corporation. 

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**FIGURE 1.** Flow sheet of mill of North River Garnet Co. 

2. Flow sheet of mill of Wausau Abrasive Co. 

3. Flow sheet of mill of The Rhodolite Co.
GARNET: ITS MINING, MILLING, AND UTILIZATION

By W. M. Myers and C. O. Anderson

INTRODUCTION

The term “garnet” is popularly associated with a dark-red, semi-precious stone that has been used for ornament since prehistoric times. Only within recent years has it been recognized that an unusual combination of physical properties makes this mineral, or, rather, group of minerals, useful to modern industry. The recognition of the abrasive qualities of garnet and the superiority of garnet as an abrasive for some purposes resulted in the active search for deposits that could be worked at a profit on a commercial scale. Such deposits have been found and are being worked by up-to-date methods; the problem of separating the garnet from its associated minerals has been solved; and the production of garnet has become a well-established industry. This bulletin presents the results of an investigation conducted by the Bureau of Mines as part of its work for the increase of efficiency and the prevention of waste in the mineral industries.

ACKNOWLEDGMENTS

The authors wish to acknowledge the hearty cooperation of all the garnet producers mentioned in this bulletin, who freely gave permission to examine their properties and furnished a great deal of technical data. Particular acknowledgment is made of the many courtesies extended by Mr. C. R. Barton, Mr. T. S. Mennie, Mr. F. C. Hooper, Mr. N. Davenport, and Mr. J. Davenport. For information concerning the use and manufacture of garnet products thanks are due to the H. H. Barton & Son Co., Herman Behr & Co. (Inc.), the American Glue Co., the Wausau Abrasive Co., the United States Sand Paper Co., the Manning Abrasive Co., and the American Gem and Pearl Co.

MINERALOGY OF GARNET

The term “garnet” is applied to a closely related group of minerals which crystallize in the same forms and have similar physical properties, although their chemical composition may vary widely.
The term “garnet” is derived from the Latin granatus, seedlike, in allusion to the appearance of the crystals embedded in their matrix. The early English term “granat” was derived directly from the Latin and it is only since the eighteenth century that the present term “garnet” has come into common use.

CRYSTALLOGRAPHY

Garnet crystallizes in the cubic system—commonly in rhombic dodecahedrons, in tetragonal trisoctahedrons, or in combinations of these forms. The hexoctahedron appears occasionally; other crystal forms are rare. Under favorable conditions garnet crystallizes in remarkably perfect forms which exhibit crystal faces rivaling the facets of a cut gem. Under less favorable conditions garnets appear either in irregular masses on which crystal faces can just be distinguished or in rounded grains disseminated throughout the rock. Occasionally the garnet is so segregated from the associated minerals that it forms large massive aggregates.

PHYSICAL PROPERTIES

The physical properties of the garnet group vary with the individual varieties, but in general fall within the following limits: Color, widely variant, from colorless and white through all shades of yellow, brown, red, and green to black; transparency, transparent to opaque; luster, vitreous, resinous, or dull; streak, white; specific gravity, 3.4 to 4.3.

Fusibility.—The fusibility is variable and depends on chemical composition. Garnets containing considerable iron fuse readily before the blowpipe to a dark glass, at temperatures near 1,300° C. Garnet containing a considerable percentage of chromium is infusible before the blowpipe. When fused by itself, garnet disassociates into other compounds. In the fused mass a number of minerals have been identified, bearing no relation to garnet other than that their chemical constituents were derived from it.

Index of refraction.—The index of refraction of the garnet group ranges from 1.735 to 1.94. As garnet crystallizes in the isometric or cubic system it has only one index. Some garnets, however, occasionally display an anomalous double refraction which is believed to be due to a complex twinning of triclinic individuals that produces forms apparently isometric.

Cleavage.—An indistinct dodecahedral cleavage has been observed rarely. Some species of garnet have a pronounced laminated structure which causes planes of weakness along which the garnet separates. This parting is mechanical, is not related to the crystal form, and hence can not be considered a true cleavage.
Fracture.—The fracture of garnet shows great variation. In some varieties, particularly those having a glassy structure, it is decidedly conchoidal, for the mineral tends to break in thin, shell-like flakes. Other varieties show the conchoidal fracture less plainly or not at all and their fracture may be termed uneven.

Tenacity.—Aggregates of garnet composed of many small individuals are brittle and shatter readily; massive garnet and well-formed crystals are remarkably tough and are shattered with difficulty.

Hardness.—The hardness of garnet ranges from 6.5 to 7.5 in Moh’s scale. Some specimens are said to have had a hardness approaching 8.0. Sound crystallized garnet generally has a hardness of 7.5; it is therefore slightly harder than quartz, which has a hardness of 7.0.

CHEMICAL COMPOSITION

The chemical composition of the garnet group may be represented by the general formula $R''_3R'''_2$SiO$_4$ or $3R''O.R'''_2$O$_5$.3SiO$_2$, in which $R''$ represents the bivalent elements calcium, magnesium, manganese in the manganous state, and ferrous iron, and $R'''$ represents the trivalent elements, ferric iron, aluminum, and chromic chromium. Rarely a part of the ferric iron or silicon is replaced by titanium. Because of the isomorphous substitution of the different bivalent and trivalent elements, specimens of garnet with a constitution that may be represented by a definite formula are rare and the composition of any given specimen is generally very complex.

The chemical stability of garnet varies greatly with composition; some garnets have been exposed on the surface of a rock outcrop for long periods of time—probably since the glacial age—without undergoing alteration. Other garnets have been completely altered and pseudomorphs after garnet are common; in these, although the original crystal form remains unchanged, the garnet has altered to scapolite, epidote, oligoclase, hornblende, chlorite, or other minerals. Garnets containing ferrous iron may disintegrate through the oxidation of the iron, which generally forms a rusty coating of limonite around fragments of unaltered garnet. Members of the garnet group have a marked tendency to include other minerals within their crystals. In some specimens this tendency is so strong that the garnet crystal is only a shell inclosing other minerals. The included minerals often are quartz, mica, or pyroxene, which are so finely disseminated that their mechanical separation from the inclosing garnet is very difficult, and to obtain samples of pure garnet for analysis is troublesome.
The garnet group is composed of six species and their isomorphous mixtures. One of these mixtures, rhodolite, which is said to exist in fairly definite proportions, may be said to constitute a seventh species. The garnet group may be further subdivided into three smaller groups in which the species of garnet are classified according to the preponderance of the trivalent elements, aluminum, ferric iron, and chromic chromium. The aluminum garnets are grossularite, pyrope, almandite, rhodolite, and spessartite. The ferric iron variety of garnet is represented by andradite and the chromium variety by uvarovite.

**Grossularite.**—Grossularite, also known as hessonite, essonite, or cinnamon stone, is represented by the formula Ca₃Al₂(SiO₄)₃. Its molecular weight is 451.7; index of refraction, 1.735; specific gravity, 3.5 to 3.7; and hardness, 6. The color shows a wide range from white through various shades of yellow and brown to red.

**Pyrope.**—The formula of pyrope is Mg₃Al₂(SiO₄)₃. Its molecular weight is 404.6; index of refraction, 1.742; specific gravity, 3.7; hardness, 7; color, deep red to black.

**Almandite.**—Almandite has the formula Fe₃Al₂(SiO₄)₃. Its molecular weight is 499.1, index of refraction, 1.778 to 1.830; specific gravity, 3.9 to 4.2; hardness, 7 to 7.5; color, red, brown, or black. The deep red variety known as carbuncle has been used as a semi-precious stone since the earliest days of civilization.

**Rhodolite.**—Rhodolite is an isomorphous mixture of pyrope and almandite in the ratio of 2 molecules of pyrope to 1 of almandite; therefore its formula is 2(Mg₃Al₂(SiO₄)₃).Fe₃Al₂(SiO₄)₃. Its index of refraction is 1.760; specific gravity, 3.80 to 3.90; hardness, 7 to 7.5; color, rose pink to dark red.

**Spessartite.**—The formula of spessartite is Mn₃Al₂(SiO₄)₃. Its molecular weight is 496.4; index of refraction, 1.800; specific gravity, 4.2; hardness, 7; color, brown to red.

**Andradite.**—Andradite, represented by the formula Ca₃Fe₂(SiO₄)₃, has a molecular weight of 509.3. Its index of refraction is 1.865 to 1.94; specific gravity, 3.85; hardness, 7; color, yellow, green, brown, or black. This variety of garnet is very common and it is an accessory mineral in many different rocks. A yellow or greenish variety of andradite is known as topazolite, an emerald green variety as demantoid, and a black variety is often termed melanite.

**Uvarovite.**—Uvarovite has the formula Ca₃Cr₂(SiO₄)₃. Its molecular weight is 501.7; index of refraction, 1.838; specific gravity, 3.5; hardness, 7 to 7.5; color, emerald green.

Schorlomite, the variety of garnet containing titanium, is too rare to be of other than scientific interest.
Specimens of garnet are usually classified under the name of the variety whose chemical composition is approached most closely. The specific gravity and index of refraction of any variety can hardly be considered constant, as both are affected by slight changes in chemical composition. The figures given in the preceding descriptions of varieties are those which have been determined for specimens whose chemical composition most closely approached the theoretical.¹

**OCCURRENCE**

The members of the garnet group are common accessory minerals in a large variety of rocks. They are particularly common in the granitic rocks, gneisses, and schists, but are abundant in contact metamorphic zones and in metamorphosed crystalline limestones, as well as in such basic rocks as serpentine and peridotite. Much garnet is undoubtedly of secondary origin, having been formed by the molecular rearrangement of the mineral constituents of sedimentary rocks under heat and pressure sufficient to dissociate the original minerals. Some occurrences of garnet in granite, pegmatite, and similar rocks seem to be primary, the garnet having crystallized out of the magma solution as one of the original rock minerals. The principal minerals associated with garnet are quartz and members of the feldspar, mica, pyroxene, and amphibole groups. Most varieties of garnet are more resistant to chemical and mechanical erosion than are the associated minerals, except quartz, and for this reason garnet associated with quartz particles that have likewise undergone little alteration are common in the detritus of disintegrated rocks and in sand deposits. Garnet has a higher specific gravity than most of the minerals associated with it and consequently it tends to concentrate at the lowest part of disintegrated and sandy accumulations. This is particularly noticeable in sand and gravel deposited by streams or along the shores of lakes.

As garnet occurs in a large variety of rocks, the geographical areas in which it may be found are enormous both in extent and in number. Concentrations of garnet possessing the necessary qualifications for ornamental or industrial use, and so situated with regard to transportation and markets that they can be exploited commercially are, however, relatively small and occur in only a few areas. Because of the comparatively small demand for garnet, development of these deposits has not been large.

Since prehistoric times specimens of garnet possessing attractive color have been used for ornaments.

In common with other gem stones that were popular in the Middle Ages, a number of magical and medicinal properties were ascribed to this mineral. It was emblematic of constancy and was believed to possess the particular virtue of dispelling poisonous and infectious airs. It preserved health, reconciled differences between friends, and when worn suspended from the neck was said to ward off plague and thunderbolts, strengthen the heart, and increase riches and honor.

Traces of the early superstitions concerning gem stones exist to-day in the custom of wearing "birth stones" which are believed to exert a beneficial effect upon the wearer. Garnet is the birth stone for January and some people still claim that its use imparts some of its magical properties to those born in that month.

Because of their abundance and their striking color, the red and crimson varieties of garnet are most commonly used as gem stones. Garnets exhibiting other colors are more uncommon and are therefore much less utilized. Yellow and orange crystals of the hessonite variety of grossularite have furnished a few fine gems, the bulk of the production having come from gravel deposits in Ceylon. In the United States hessonite of excellent quality has been found in San Diego County, Calif.

The fiery red pyrope is undoubtedly the most popular variety of semiprecious garnet and constitutes the chief supply because of its abundance in the Bohemian Mittelgebirge near the towns of Tep- litz and Aussig, which are approximately 60 kilometers north of the city of Prague in Czechoslovakia. This is probably the only place in the world in which the collection and preparation of gem garnet for the market has been of sufficient importance to approach an established industry. The diamond mines at South Africa have produced many fine pyrope garnets as a by-product. Pyrope of excellent quality is abundant in the Navajo Indian reservation in Utah and Arizona. The most important producing areas are the Mule Ear and Moses Rock fields in southern Utah, and the Garnet Ridge field in the adjacent part of Arizona. Here the garnet is scattered through the sands and gravels in small crystals that have been rounded by the scouring action of wind-blown sand. The crystals are collected from the surface by the Indians and sold in small lots to tourists and traders. It is believed that these garnets were liberated by the decomposition of a garnetiferous schist or
gneiss. Pyrope has also been found in New Mexico, Kentucky, Colorado, California, Madagascar, Ceylon, Brazil, and many other widely distributed localities.

The crimson almandite has furnished some fine gems which are generally cut en cabochon because the depth of the color makes a faceted stone appear dark and lifeless. This type of garnet is more commonly known as carbuncle, and has been used extensively for ornament since very early times. Bohemia, Ceylon, Madagascar, India, Brazil, and Alaska have furnished considerable almandite of gem quality. In the United States it has been found in many localities, particularly in Pennsylvania, New York, North Carolina, Colorado, and California.

Rhodolite suitable for gems has been found in only one locality; practically the entire production has come from Macon and Jackson Counties in the western part of North Carolina. Many beautiful gems have been cut from the pale-red and rose-colored garnet obtained there. These stones are exceptionally brilliant and their pleasing color has increased their popularity.

Very little spessartite has been found in crystals having the transparency, color, and size that would make them of value as decorative stones. The only locality in the United States which has produced any appreciable amount of this stone is Amelia Courthouse, Amelia County, Va., where a few orange-brown stones of good quality have been found. Spessartite of gem quality has been reported in Nevada and a few crystals have been found in Ceylon.

Until a few years ago andradite was not considered to have any possibilities as a gem stone and it was not utilized for decorative purposes until the discovery of the green variety known as demantoid. This variety is found in Russia on the western side of the Ural Mountains, where it occurs in small crystals ranging in color from olive to emerald green. The deep green varieties were at first confused with the genuine emerald, until their true nature was revealed by chemical analysis. The brilliant luster and great color dispersion of demantoid add to its beauty as a gem.

Although uvarovite of a pleasing green color has been found, it has not been utilized as a gem stone because crystals large enough for cutting are exceedingly rare. According to a recent report, considerable quantities of massive uvarovite suitable for ornamental purposes has been found in the Bushveld in Western Transvaal, chiefly on Buffelsfontein No. 205 about 6 miles from Wolhuter Station on the Pretoria-Rustenburg Railroad, 40 miles west of Pretoria. This deposit has been prospected by short trenches and shallow excavations to a maximum depth of 9 feet. Chromite is

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2 Hall, A. L., Chrome-garnet from the western Transvaal Bushveld; South African Min. and Eng. Jour., Sept. 27, 1924, pp. 63-64.
intimately associated with the uvarovite. The occurrence is of enough promise to warrant exploitation and the product is now being marketed under the trade name of South African “jade.” It is homogeneous and even textured and no individual minerals can be identified with the naked eye except where the chromite is present. The range of color is wide; shades of green are most common, and some pink, white, and bluish specimens have been found. The hardnes, which ranges from 7 to 8, enables the “jade” to take an excellent polish when worked. The deep-green translucent varieties are most valuable because of their resemblance to the true jade, which is highly prized by the Chinese. Several lots have been sold in the Far East at a figure in excess of that paid for crude Burmese jade.

It has been estimated that in 1922 the world’s production of gem garnet was worth $68,000.*

MINING OF GEM GARNET

Mining for gem garnet has never developed into a systematic, well-established industry in any one locality for two reasons: (1) The enormous geographic distribution of garnet deposits tends to localize the market and to prevent any one deposit from supplying the bulk of the world’s demand, and (2) the present buying capacity of the public can be satisfied by a few small and scattered operations. Garnet is one of the cheapest gem stones and commands so low a price that its extraction is seldom profitable. The small amount of gem garnet produced annually is obtained from small quarries that are worked irregularly or is collected from superficial deposits formed by the disintegration of garnetiferous rocks. In the quarries the rock is drilled by hand and shot with small charges of explosives, so that it can be removed and be broken down carefully by hand to liberate the garnet crystals without shattering them. As its shattering effect is less, black powder is preferable to dynamite as an explosive. Quantities of garnet have been freed by the weathering and disintegration of garnetiferous rocks. Considerable garnet of gem quality has been collected from loose sand and from stream gravels in which this liberated garnet had concentrated. A few crystals of garnet of gem quality are occasionally recovered as a by-product in the mining of abrasive garnet and in the operation of gold placers.

PRODUCTION IN UNITED STATES

Some garnet was undoubtedly used for ornament by the early European settlers in America. The literature of colonial days contains very few references to the mineral, and interest aroused in it probably did not extend beyond the occasional collection of a crystal.

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of unusual perfection or attractive color. One of the early references to American garnet is contained in “An Essay about the Origine and Virtues of Gems,” by the English chemist, Robert Boyle, which was published in 1672. In discussing the origin of minerals Boyle says:

I have some American granats which I had a great and peculiar reason to believe had been once liquid bodies, and therefore thought them the more worthy to be examined; and finding their color to be so deep that they were almost opacous, and by judging by my hand that they were much heavier than pieces of cristal (quartz) of the same bulk would be, I weighed them in a pair of nice scales in the air and in the water, and found them, as I had expected, to be almost four times as heavy as water of the same bulk.

This specific gravity determination indicates that the garnet in question was probably almandite.

The records of the production of gem garnet in the United States indicate the unimportance of this market, as the annual output has seldom had a value exceeding a few thousand dollars.

*Value of gem garnet produced in the United States*

[Statistics from the U. S. Geological Survey]

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In 1900 rhodolite valued at $20,000 was produced in North Carolina; in 1901 the production was valued at $21,000; this rhodolite accounts for the unusually high figures for the two years. Since 1901 the production of garnet has declined to a figure so unimportant that no records have been kept since 1921.

**AS A JEWEL FOR BEARINGS**

Garnet has been used to a limited extent as a jewel in the bearings of watches, meters, and scientific apparatus. The material employed for this purpose must be hard enough to withstand the wear caused by the friction of moving parts and tough enough to be manufactured into thin slices that will not shatter under rough handling. Most of the garnet used for bearings consists of the chips produced during the cutting of gem garnet from Bohemia and Mada-
Garnet: Its Mining, Milling, and Utilization

g Barker. These chips are ground down until very thin, given a rounded form, and then pierced in the center with a small drill. Before the jewels are set in a watch the opening is redrilled to make it fit accurately the axle which rotates on this bearing. Sapphire and ruby—the blue and red varieties of corundum—are considered better than garnet for bearings, as they are harder and consequently more durable, and they are therefore used more extensively. Millions of these jewels are annually used in watch movements. Garnet is used only in the cheaper movements, but the number of garnet jewels used monthly in watches is estimated at 250,000. Jewels are made in Switzerland, which supplies the greater part of the world’s requirements. Aside from a very small production during the World War, when imports were curtailed, no garnet for jewel purposes has been produced in the United States. The supply from foreign sources has been abundant and has sold at a price below the cost of domestic production.

For the Manufacture of Ferrosilicon

The elements that compose garnet are not of enough value to make their extraction profitable. Extraction would necessarily be difficult and expensive because of the stability of the silicates composing the garnet group. As far as is known only one attempt has been made to utilize the chemical composition of garnet. United States Patent 1192394, issued July 25, 1916, describes a process for the manufacture of ferrosilicon and a highly aluminous abrasive from almandite garnet. The patentee proposed to utilize the considerable quantity of garnet flour produced in the manufacture of garnet abrasives. This powder was too fine for use as an abrasive, and there was no market for it in 1916. The process consisted in the reduction of the garnet in an electric furnace. The furnace charge was garnet crushed to one-sixteenth inch or less, mixed with approximately 18 per cent of its weight of carbon. An alternating current of low voltage and high amperage was supplied to the electrodes, one set in the base of the furnace, the other, a graphite rod that could be raised or lowered, suspended vertically in the center of the charge. The amount of carbon added to the charge was sufficient to reduce all the constituents of the garnet except the alumina; enough silica was added to insure the conversion of the iron content of the garnet to a ferrosilicon alloy. The charge in the furnace was heated to the fusion point of alumina and maintained at this temperature until all of the garnet constituents except alumina were reduced. Then the charge was cooled slowly, so that the alumina could crystallize and the ferrosilicon solidify in nodules.
A description of the experimental work employing this process says that a ferrosilicon alloy containing 24 to 25 per cent silicon and an aluminum abrasive containing about 62 per cent alumina could be produced from the original garnet.

The process was devised when ferrosilicon was expensive and difficult to obtain because of war-time conditions. It is doubtful if the process would be feasible at present, as ferrosilicon is abundant, whereas garnet is too expensive and is hardly sufficient to maintain such a process on a commercial scale.

AS AN ABRASIVE

Present activity in the mining of garnet has resulted from recognition of the unusual abrasive properties of the mineral. The bulk of the garnet mined for use as an abrasive has been almandite; rhodonite, pyrope, and andradite have been utilized to a lesser extent. Deposits of the other varieties which could produce a commercial tonnage of abrasive garnet are unknown. Abrasive garnet is utilized either in the form of a manufactured paper, similar to sandpaper, or as a loose grain or powder for grinding and polishing. The average hardness of abrasive garnet is 7.5, but some specimens have shown a hardness approaching 8.0. Quartz that is used for the manufacture of ordinary sandpaper is not as hard; it has a hardness of 7.0. The marked lack of any regular cleavage and the manner in which the mineral fractures affect the shape of the grains of crushed garnet and thereby influence its industrial use.

Although much garnet has a laminated structure, which furnishes parting planes along which the mineral separates when crushed, this structure can not be considered true cleavage because the garnet shows no further tendency to part regularly when it has once been separated into the plates formed by these laminations. Furthermore, this parting is purely mechanical and is not related to the crystallization. Garnet used as an abrasive has a fracture that is irregular to subconchoidal, consequently the grains of crushed garnet are irregular, many-angled particles which are roughly equi-dimensional and suggest modified cubes or tetrahedrons which have a multitude of sharp chisel-like cutting edges. As these grains break in use further sharp edges are produced. Garnet seems to have just enough brittleness to break under the strain of ordinary use rather than to wear down to a smooth surface.

Substances having a distinct conchoidal or shell-like fracture, of which glass is a typical example, shatter into fragments that tend to be flat and very thin. Although these flat particles retain very

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sharp cutting edges, it is impossible to arrange them on paper in such a manner that they will make an efficient abrasive. Either they tend to lie flat on the paper or else they project in long splinters which make deep scratches in the material being ground or polished. These scratches are highly objectionable, as their removal requires further grinding and polishing and thus increases the cost. Particles of garnet have enough flat surfaces to permit firm attachment to the paper backing; at the same time they expose a number of cutting edges which are practically in the same plane and therefore abrade evenly. Powdered garnet is used chiefly for grinding plate glass; here its greatest asset is its hardness, which enables it to abrade the softer glass with rapidity.

DEVELOPMENT OF THE ABRASIVE GARNET INDUSTRY

The initial developments in the mining of garnet were due to the perception of the late Mr. H. H. Barton, of Philadelphia, Pa. According to a letter from Mr. C. R. Barton to the writers, he first recognized the abrasive properties of the mineral and realized their commercial importance. It is interesting to note in this connection that the utilization of garnet as an abrasive is in a degree an outgrowth of its use as a gem. During the period from 1860 to 1865, while Mr. Barton was in business as a jeweler in Boston, Mass., his attention was attracted to garnet by a gentleman who brought in a small amount to be appraised for its gem value. This garnet was from the Adirondack section of New York State. Although the mineral was of good quality, it was thought that the market was too small to permit a domestic product to compete with the importations of gem garnet from Bohemia, so the matter was dropped and for the time was forgotten.

Some years later Mr. Barton engaged in the manufacture of sandpaper from crushed quartz, flint, and, to a lesser extent, glass. Keen competition resulted in the investigation of possible improvements. For a time a new abrasive paper known as “ruby paper” was manufactured, in which the quartz was replaced by red carnelian, a form of silica closely related to agate. This carnelian was collected in California. The supplies were limited, the delivery uncertain, and eventually the use of carnelian as an abrasive was abandoned.

In continuing the search for an improved abrasive the possibilities of garnet were investigated. Its superior qualities were quickly recognized and a search was begun for a deposit capable of commercial production. Mr. Barton remembered the gem garnet from the Adirondacks of New York, and located the deposit from which the small sample had been taken years before. As this deposit
proved to be very large and rich in garnet, the manufacture of garnet paper on a commercial scale was undertaken. Garnet paper was first made about 1880 and began to be of commercial importance about 1882.

Contemporaneous with this development Herman Behr & Co. (Inc.) opened a deposit of garnet near Boothwyn, Delaware County, Pa. This garnet occurred in a mica schist which extended from the surface to a depth of 30 or 40 feet. The garnet content was high, averaging 30 per cent of the rock mass. The surface of the rock was so disintegrated that down to 20 feet the garnet could be extracted readily. Below 20 feet the rock was unaltered, the separation of the garnet became more difficult, and milling operations were started. This was the first attempt to mill garnet ores, as the previous output had been obtained by hand copping the disintegrated rock. The harder garnet-bearing rock mined later was broken by mulling and placed in a washing machine that separated the garnet from the dirt and gangue. Operations at Boothwyn were abandoned in 1898 as garnet of better grade became available from other sources. A small quantity of garnet was also produced by underground mining in a decomposed gneiss near Chester Heights, Delaware County, and by small workings in Chester County, Pa.

The recognition of the value of abrasive garnet resulted in the search for other deposits and operations were started in Connecticut, North Carolina, and New Hampshire. The Connecticut deposits, near Roxbury and Roxbury Falls, were eventually abandoned after being worked for a time on a small scale and New York, New Hampshire, and North Carolina remained the only producing States.

ADVANCES IN MINING AND MILLING

The first milling of garnet ores on a comparatively large scale was done by Mr. F. C. Hooper, who established the North River Garnet Co. at North River, N. Y. Separation of garnet from associated minerals by mechanical means on a large scale had received little attention until 1893, when the first mill of the North River Co. was erected. The principles and equipment of standard metal practice were adapted to meet the particular requirements of garnet milling, and special machines were designed to treat such special mill products as could not be properly handled with the equipment available. Accompanying the development of better equipment for milling garnet ores came more systematic methods of mining. Large quarries were opened, hand drilling and loading were abandoned,
and mechanical equipment replaced the older and slower methods of
handling the ore. New York now holds a dominant position in the
production of garnet because of the early development of the indus-
try in that State and the abundance of high-grade ores in the Adiron-
dack district. Garnet-bearing rocks occur over a wide area in War-
ren, Essex, and Hamilton Counties and especially in the district
adjacent to the intersection of the boundaries of these counties. The
garnet is in fairly well-developed crystals and also in large massive
aggregates showing little trace of individual crystallization. Most
of the rocks are gneisses and have undergone extensive metamor-
phism. Their origin is uncertain. In some localities the rocks seem
to be much altered sediments, in other places they seem to be of
igneous origin. The garnet content of the rocks seldom exceeds a
maximum of 12 per cent, although the massive aggregates are oc-
casionally found in large masses containing as much as 60 per cent
garnet. In spite of the wide distribution of the rocks, garnet con-
centrations rich enough to make the rock commercially important
are not common and are found in comparatively few localities.

The present production of this district is limited to the operations
of four companies—the North River Garnet Co., Barton Mines
(Inc.), the Warren County Garnet Co., and the American Glue Co.
In the past a number of small scattered workings have produced
irregularly but none of them are active to-day.

DESCRIPTONS OF MINES AND MILLS

NEW YORK

THE NORTH RIVER GARNET CO.

The operations of the North River Garnet Co. are on the eastern
side of Thirteenth Lake, in Warren County, N. Y., about 10
miles from the village of North Creek, which is the terminus of the
Adirondack branch of the Delaware & Hudson Railroad and the
nearest shipping point. Motor trucks running over State and pri-
vately owned roads carry in supplies and bring the garnet concen-
trates from the mill to the railroad for shipment.

QUARRY

The garnet, which approaches almandite in composition, occurs in
a gneiss which apparently is a metamorphosed sediment of the Gren-
ville series. The garnet content of this gneiss ranges from 4 to 8 per
cent, and is in crystals that attain a maximum diameter of 3 inches,
but average about five-eighths inch. Hornblende and feldspar are
the most important gangue minerals, but pyroxene, mica, magnetite,
pyrite, and ilmenites are present in small amounts. A large project-
A. QUARRY OF THE NORTH RIVER GARNET CO.

B. MILL OF THE BARTON MINES CORPORATION
ing knob of this gneiss has been opened by a pit 300 feet in maximum diameter. The face of this quarry is 140 feet high at the highest point. The rock shows highly developed joint systems (see Pl. 1, A) and the horizontal partings are utilized for the base of small benches in quarrying. Systematic large benches are not developed. Shot holes are drilled with power drills to a depth of 15 feet. The holes are sprung and then loaded with 60 per cent ammonia dynamite, which is fired with a blasting machine. The jointing of the rock tends to produce large blocks and considerable blockholing is necessary. The drilling for this is done with machine drills and the holes are loaded with 40 per cent dynamite. Car tracks, 36-inch gauge, run from the working faces to the head of the mill, a maximum distance of 200 yards, on a grade that permits the loaded cars to run by gravity. A horse draws back the empties; the broken rock is either loaded by hand into a double open-end car with a capacity of 8 tons or is moved with a steam shovel. Two power shovels with dippers having a capacity of seven-eighths of a yard are used; they load the rock into special cars with a capacity of 8 tons. Severe weather interferes with the operation of the quarry in winter.

MILL

The mill,6 which stands on a hillside just below the quarry, has a capacity of 500 tons a day. Milling consists essentially in liberating the garnet from the gangue minerals by stage crushing and concentrating it with jigs. Harz and James jigs are used for the coarser sizes; the fines are recovered on vanning and pneumatic jigs specially designed for this purpose by Mr. F. C. Hooper. Figure 1 shows the flow sheet of the mill. Dry, stage crushing with jaw crushers and rolls reduces the rock to fragments one-quarter to five-sixteenths inch in size which go to a storage bin with a capacity of 200 tons. From this bin the ore is fed by water to Harz jigs pulsating two hundred times per minute and provided with one-quarter and three-sixteenth inch screens. These jigs make a clean tailing, which immediately goes to waste, and a middling hutch product which, after being partly dewatered in cones, goes to four James jigs pulsating two hundred and twenty-five times per minute, and one Hooper vanning jig. These jigs, all provided with 6-mesh screens, make a clean tailing, a middling, and hutch product. The hutch product goes to a series of vanning jigs so arranged that the hutch product from one jig is the feed for the next. The screens of these jigs are 12, 16, 22, and 30 mesh. Except the jig having a 12-mesh screen, the jigs produce a clean concentrate which is skimmed

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Figure 1.—Flow sheet of mill of the North River Garnet Co.
and removed by hand. The middling produced is sent to a Wilfley table which makes a clean tailing, which is sent to waste, and an enriched middling. This middling goes by an elevator to a steam drier; after drying it is screened through 40, 52, and 68 mesh screens. The minus 68-mesh material goes directly to waste. The other products are concentrated on pneumatic jigs which produce a concentrate, middling, and tailing. The middling is returned to the pneumatic jigs.

An elevator takes the middling from the four James jigs and the single Hooper vanning jig to a single-cell James jig which makes a clean concentrate and a middling which goes to a set of Hummer screens. These screens size the material to 3½, 5, and 10 mesh. The middling product from the vanning jigs having a 12-mesh screen also goes to these screens. Rolls crush the oversize from the 3½-mesh screen and also the skimmings from the Harz jigs which have passed a 2-mesh screen. These rolls are in closed circuit with the Hummer screen. The plus 5 mesh goes to a James jig having a 6-mesh screen, which makes a concentrate and middling. The plus 10 mesh goes to a two-cell James jig, provided with 12-mesh screens, which makes a concentrate, middling, and tailing. The middling from the 6-mesh and 12-mesh jigs is recrushed in the rolls and sent to the Hummer screen. The minus 16 mesh goes to the 16-mesh vanner jig where it joins the circuit of the 22 and 30 mesh jigs.

An elevator carries all the concentrates to an inclined steam drier which discharges into a bin that receives the mixture of all the different concentrate products. This final concentrate averages 90 per cent garnet. It is sacked and then trucked to North Creek for shipment by rail. Three 150-horsepower coal-fired Stirling boilers supply steam to a tandem Corliss-valve engine which drives the mill.

Part of the tailings are utilized for road construction. They also make an excellent concrete aggregate but are not valuable enough for this purpose to warrant transportation beyond the immediate locality.

THE BARTON MINES CORPORATION

The mining and milling operations of the Barton Mines Corporation are situated on Gore Mountain at an altitude of 2,800 feet, about 4½ miles southwest of the village of North Creek, N. Y. By road the distance is approximately 11 miles and in places the grade is high, as there is a rise of 1,800 feet in approximately 3 miles. Trucks bring in supplies for the camp and carry the garnet concentrates to the railroad.
QUARRY

The ore body has a general east-west strike, and its outcroppings have been traced a total length of more than 4,000 feet; its total extent is unknown. The overburden is slight. Quarrying operations have exposed the ore body for a length of 2,000 feet and a breadth of 150 feet.

The garnets occur in a metamorphosed igneous rock of uncertain origin but seemingly allied to syenites that are common in the vicinity. The rock shows little banding or schistosity, its most marked feature being the garnet crystals which give it a porphyritic texture. The mineralization is simple. Hornblende constitutes nearly 40 per cent of the mass; almost all the remainder is divided between orthoclase and plagioclase feldspars, pyroxene and biotite. Small amounts of magnetite, pyrite, and ilmenite are present. The garnet content of the ore body averages 12 per cent in the areas exposed by quarrying. The garnet occurs as imperfectly developed crystals, locally called "pockets," which attain remarkable size. Single crystals 1 foot in diameter are common; crystals 30 to 36 inches in diameter have been found and have yielded over a ton of garnet. Most of the crystals are surrounded with thin shells of pure hornblende, to which are attached masses of pale green plagioclase feldspar, approaching oligoclase in composition, which indicate fractional crystallization of the rock as it solidified. Conditions must have been exceptionally favorable to prolonged crystal growth to permit the development of crystals of a size unparalleled in other deposits. These garnet crystals have a decided laminated structure by which they are readily divided into plates from one-sixteenth to one-quarter inch thick. A thin film of pyrite or other mineral often lies in the lamination. The garnet approaches almandite in composition.

Weathering has altered the garnetiferous rock near the surface and the oxidized zone has developed to a depth of 15 feet. In this oxidized zone the feldspars are completely kaolinized, and the hornblende has been altered until a siliceous, iron-stained residue is left. The garnet in the oxidized zone shows practically no indications of change other than a tendency to break readily along the lamination planes, which have been weakened by the alteration of the separating films of pyrite and other minerals.

The first mining, which began over 40 years ago, was in this oxidized zone. Because the ore was crumbly it could be readily worked with pick and shovel and the garnet extracted by hand. Mining operations were carried on irregularly by lessees who sold their productions to buyers of abrasives. The production was small, not more than 900 tons a year. At a later date mining of the unoxidized
rock began, and when the erection of a modern concentrating mill was completed in March, 1924, this mining was systematized.

The quarry now consists of a series of open pits which are being developed into regular benches. Mining is most active on two faces, one of which attains a maximum height of 22 feet. Ten-foot holes, drilled with jack hammers, are blasted with 40 and 60 per cent gelatine. More drilling is done on the bench developed by shooting the first set of vertical holes, and when these are shot the face is advanced. A large number of drill holes, totalling several hundred feet, are drilled in the floor of the quarry back of the advance face. Bowlders are block-holed with small charges of dynamite. In breaking the ore many of the garnet crystals are shattered. The largest fragments of clean garnet, which amount to several hundred pounds a day, are picked up and sacked immediately for shipment.

The broken ore is loaded into 3-ton side-dump cars with a steam shovel mounted on caterpillar treads and having a capacity of three-fourths cubic yard. A gasoline locomotive hauls four-car trips to the mill 200 yards distant. Plate I, B, gives a view of the mill. Plate II shows the flow sheet of the mill.

MILL

At the top of the mill the cars dump into a chute with a slope that is less than 45 degrees to provide a dirt floor and avoid abrasion. From this chute the ore passes to a 24-inch by 36-inch Blake-type jaw crusher with a 3-inch gap. Railroad rails suspended just in front of the crusher check the rush of the largest bowlders. A short belt feeder takes the crusher discharge and drops it into an elevator which delivers it to a double trommel, the inner jacket of which has 13\(\frac{1}{4}\)-inch holes and the outer jacket 3\(\frac{3}{4}\)-inch holes (round). The undersize passes to the storage bin; the oversize goes to a picking belt where the large pieces of garnet are removed and also much tramp material. A magnetic pulley at the discharge end of this belt removes tramp iron. The belt discharges into a gyratory crusher which is in closed circuit with the elevator and the double trommel. Hence, the storage bin contains ore that is all through three-fourths inch. Although the grinding is presumably dry, the moisture content of the ore is such that there is very little dust. As the capacity of the bin is about 500 tons it is proposed to do all of the crushing on the day shift and run only the concentrating part of the mill 24 hours a day.

The storage bin discharges through five hoppers to a flat conveyor, driven by a ratchet arrangement, which delivers the ore to the main feed elevator. At the end of this belt water is added
for the first time. The elevator discharges to a chain drag which
dwaters the material before it passes to a series of five trommels.
The overflow of the drag goes through a chip catcher to the Dorr
thickener. The five trommels are arranged in this order: One-half
inch, three-eighths inch, one-fourth inch, one-eighth inch, and 2\(\frac{1}{2}\)
millimeters. The chain drag discharges first to the one-half-inch
trommel, and the oversize from that goes to a 30-inch by 16-inch
set of rolls which is in closed circuit; consequently, all of the ore
passes through one-half-inch round hole before concentration be-
gins. The undersize from the one-half-inch trommel passes to the
three-eighths-inch trommel, and the undersize of that to the one-
fourth inch. The four sizes of concentrates made by the series
of trommels are each fed to three-compartment jigs. The first
size, minus one-half inch plus three-eighths inch, is fed to two of
these three-compartment jigs, as is also the second size, minus
three-eighths inch plus one-fourth inch. The third size, minus one-
fourth inch plus one-eighth inch, is of such volume, however, that
three of the three-compartment jigs are required to treat it. The
finest size, minus one-eighth inch plus 2\(\frac{1}{2}\) millimeters, is so small in
quantity that it requires only one three-compartment jig. Eight
three-compartment jigs are required to treat these four sizes. The
jigs run at high speed with a short stroke. The depth of bed
ranges from about 1\(\frac{3}{4}\) inches to about 3\(\frac{1}{2}\) inches. The jig sieves
are light trommel sheets with round-hole openings about 1\(\frac{1}{2}\)
millimeters to 3 millimeters in diameter. The jiggling area in
each compartment is about 24 inches by 36 inches. The first two
cells of each of these eight jigs produce clean or finished con-
centrates over the cup draw; the third cell produces a finished
tailing, which goes to the tailing elevator, and an unfinished mid-
dling over the cup draw. All of these middlings pass back to the
main feed elevator. The middlings from the jigs treating the
coorser sizes pass to this elevator through the rolls grinding the
oversize from the one-half-inch trommel.

The undersize from the 2\(\frac{1}{2}\)-millimeter trommel passes to a cone
where it is dewatered; the overflow passes to the Dorr thickener,
through the chip catcher, and the sands are fed by a distributor
to four tables, which produce a finished tailing, a middling
that goes to the elevator feeding the second set of tables, and a low-
grade dirty concentrate which is fed without dewatering to four
small one-compartment jigs; these jigs produce a finished concen-
trate through the cup draw, an unfinished tailing over the sides of
the cell, and an unfinished hutch product through the jig sieve
or bed. Part of the bedding on these jigs is small bird-shot. The
tailings and the hutch product are combined and join the table
middlings from the first set of tables; they are elevated, dewatered in a cone, and fed by a distributor to a second set of four tables which produce a finished tailing, an unfinished or dirty concentrate which is sent to the four small jigs for final cleaning, and a middling which is returned to the elevator handling this table feed. Thus these two sets of tables and the four small jigs are in a double circuit. The tailings from the eight tables and from the eight jigs treating sized feeds are elevated and dewatered in a duplex classifier, the discharge of which passes to the tailing pile, and the overflow goes to the Dorr thickener, measuring 40 feet by 10 feet through the chip catcher, an ingenious arrangement consisting of a trommel sheet and scrubbing brushes on a chain drag for removing wood pulp, waste, etc. The spigot product of the Dorr thickener goes to waste, but all of the overflow water is reused in the mill. The concentrates from all the jigs are elevated and dewatered in a simplex classifier. The dewatered concentrates pass to an oil-fired drier. The dried product is weighed into 100-pound sacks and stored in the basement until shipped. Trucks haul the finished concentrates to North Creek for rail shipment to manufacturers of abrasives. A ball mill is being installed to mill the finer sizes, for which there is a small market, to abrasive powder suitable for grinding plate glass. The tailings are used to repair the roads. They would make a satisfactory concrete aggregate but no local market is available.

Two 130-horsepower vertical two-cylinder oil engines furnish power. One drives the air compressor and the crushing or dry part of the plant; the other drives the wet or concentrating part of the mill and a 60-kilowatt generator. Either engine can be used to drive either part of the mill—a very flexible arrangement. The oil fuel flows to the engines from a tank outside the building.

In the summer months the mill is hard pressed for water. Virtually all of the water used is reclaimed by means of the Dorr thickener. The tailings are almost dry when discharged just outside the mill. Fresh water is used only for the engines and the crusher jackets and compressor. During the winter, or for about eight months of the year, the water requirements can be met with fresh water from the mountainside.

WARREN COUNTY GARNET MILLS (INC.)

The Warren County Garnet Mills (Inc.) works a number of small, scattered quarries near Wevertown and Johnsburg, N. Y. The present output is obtained mainly from the Armstrong farms in Johnsburg. The garnet occurs in broad bands in a biotite gneiss. Much of it is in massive aggregates, which in places constitute nearly the whole rock mass. Feldspar, biotite mica, pyroxene, and
hornblende are associated minerals. In some other deposits that have been worked irregularly the garnet is in well-developed crystals.

Mining is by excavations that seldom exceed 8 feet in depth. The rock is drilled by hand with a single jack, blasted, sledged, and hand picked. The rich garnet ore is separated and piled in walls so that the tonnage can be determined by measurement and is hauled to the mill by trucks. The garnet content of the ore going to the mill is high, ranging from 30 to 60 per cent.

The ore is concentrated in a dry mill with a capacity of 3 to 5 tons of concentrate a day according to the garnet content of the ore. At the mill the ore is fed by hand to a small jaw crus her from which it goes to two sets of rolls in series where grinding through about 16 mesh is completed. Screens for removing the fines are in place in front of each set of rolls. From the rolls the ore passes to a Keedy sizer which screens it into 16 sizes between 16 and 200 mesh. The 16-mesh oversize is discarded as it is mainly flaky biotite which can not be ground readily. Each of the sizes is treated separately on pneumatic tables, which are adjusted as to speed, length of stroke, and air pressure for each size handled. The concentrates and the middlings from the tables are marketed; the tailings go to waste. The middlings are sold to produce low-grade abrasives. A home-made sizer is often used to "true" or "prove" the products made by the Keedy sizer. The biotite tailing is kept separate but the quantity is so small that it does not constitute a source of supply for roofing material. The finished concentrate is shipped in kegs to wood-working industries and to manufacturers of abrasives.

THE AMERICAN GLUE CO.

A band of garnetiferous gneiss outcropping on Casey Mountain about 5 miles northwest of North River, N. Y., the nearest post office, has been operated by the American Glue Co., and has produced a considerable tonnage of garnet. In August, 1924, the mill was not active and only a small tonnage was being hand cobbled and sacked for shipment at the quarry.

The garnet (almandite) occurs in the gneiss as small crystals from \(\frac{1}{2}\) inch to 3 inches in diameter, which form 4 to 8 per cent of the rock. The outcrop of the gneiss has been traced about 2,000 feet; it is partly hidden by a shallow overburden of loose soil. In addition to an open quarry there is an underground mine. A tunnel over 800 feet long was driven from near the mill to a point below the quarry floor with which it was connected by raises. The raises were filled with broken ore from the quarry and drawn when bad weather made quarrying impossible. A considerable tonnage was also obtained from underground stopes. The rock stood well and no timber-
ing was necessary but the cost of underground mining was considerably higher than that of quarrying.

At the mill, which follows the general plan of other garnet concentration mills in this district, the ore was crushed to minus five-eighths inch plus one-half inch and treated in Harz jigs. These jigs gave a finished tailing, which was sent to waste, and a concentrate, middling, and hutch product. The middling and hutch product were crushed in rolls and screened to sizes ranging from minus $\frac{1}{2}$ inch to minus 3 millimeters. These sized products were treated in a series of jigs and Wilfley tables. The finished concentrate was dried in a steam drier, sacked, and hauled in trucks to North Creek, 11 miles distant, for railroad shipment.

OTHER MINES

A number of garnet deposits in the Adirondacks have been worked irregularly in the past but are inactive to-day. They are scattered over a wide area in Warren, Essex, and St. Lawrence Counties. In Essex County deposits near Keeseville and Minerva have yielded a small output. Small workings near North Creek, North River, Riparias, and Warrensburg, Warren County, have also produced a limited tonnage. One mine near Gouverneur, St. Lawrence County, was active for a time. At these deposits the garnet was taken from irregular excavations and no concentrating mills were erected.

The active producers of abrasive garnet in the Adirondacks control, by lease or ownership, large reserves of garnetiferous rock in addition to the deposits from which they get their present output.

NEW HAMPSHIRE

WAUSAU ABRASIVE CO.

The garnetiferous rock worked by the Wausau Abrasive Co. outcrops near the top of Currier Hill in North Wilmot, Merrimac County. The garnet (almandite) occurs in small crystals one-fourth to three-eighths inch in diameter. These small crystals constitute 40 to 60 per cent of the rock. Feldspar and biotite are the most prominent gangue minerals.

There is practically no overburden and quarrying is done in the exposed outcrop. The quarry workings are irregular because inclusions of barren rock must be avoided. The present quarry measures approximately 100 by 180 feet with a maximum depth of 25 feet. Holes are drilled to a depth of 6 feet with jack hammers and shot with 60 and 75 per cent gelatin dynamite. The bowlders are bulldozed and loaded by hand on cars with a capacity of 2,400 pounds. A hoist pulls the car up an incline from the quarry floor, and then they are trammed by hand about 300 feet to an ore bin on the edge of the
hillside above the mill. From the bin the ore is fed to a 6-inch by 10-inch jaw crushe with a 1¼-inch gap. The crushed rock falls into a loading bin from which an aerial tramway, 1,200 feet long, conveys it to the mill bin 225 feet below.

All concentrating operations are dry and consist essentially of stage crushing, screening, and concentrating the sized products on tables. Figure 2 gives the flow sheet of the mill. The ore from the mill bin is crushed in 26-inch by 15-inch rolls to three-eighths inch, and then elevated to a direct-heat drier. If the ore is already dry it can be sent directly to the screens by means of a screw conveyor, and in this way the capacity of the mill can exceed the tonnage the drier can handle in 24 hours.

The discharge from the drier goes to a Newago 4-mesh screen. The undersize, under 2 millimeters, is sent to a bin and the oversize is recrushed in 26-inch by 15-inch rolls, set to crush to 2 millimeters. The product from these rolls joins the minus 2-millimeter product from the 4-mesh screen. This 2-millimeter product is elevated to another Newago screen, divided into two sections having 6-mesh and 10-mesh screens. Two oversize products are made, one minus 2 millimeters, plus 1.4 millimeters; the other minus 1.4 millimeters, plus 0.75 millimeter. The undersize, minus 0.75 millimeter, goes to another 24-mesh Newago screen. The oversize, minus 0.75 millimeter plus 0.36 millimeter, is separated and the minus 24 mesh is passed to a 48-mesh screen which separates a minus 24-mesh plus 48-mesh product that is saved for concentration. The minus 48-mesh material goes directly to waste. The sized products are stored in bins and are treated alternately on two dry tables that are adjusted to concentrate the different size products. Tailings go directly to waste; middlings return to the 6-mesh and 10-mesh screens. The concentrates go to the sacking room, in the basement of the mill, where they are put in 100-pound canvas bags; then they are hauled by truck 3 miles to South Danbury for railroad shipment. The present output of the mill, when running one 10-hour shift a day, is 50 tons of concentrate a week. Severe weather in winter interferes with operations and production is curtailed between December and April.

A small Hardinge mill in closed circuit with a 30-inch air classifier has been installed to make garnet powder, 200 mesh to 325 mesh or finer, for use in the fine grinding of plate glass and similar substances. Any excess of any size in small demand is utilized in this way. In August, 1924, a grading plant was being installed at the mill to prepare garnet that could be shipped instead of the concentrate of mixed sizes.

In addition to the active quarry operation, the company owns other deposits which provide a considerable reserve.
Figure 2.—Flow sheet of mill of Wausau Abrasive Co.
FORD MOTOR CO.

The Ford Motor Co. has acquired a deposit of garnetiferous rock about 1½ miles from Danbury, N. H., which is much similar to the deposit worked by the Wausau Abrasive Co. The garnet occurs in small crystals and in places constitutes as much as 60 per cent of the rock. In August, 1924, only a little development had been done. From a small, irregular excavation in one of the outcrops in the hillside about 100 tons of garnet-bearing rock were removed for shipment; then active work was suspended.

NORTH CAROLINA

THE RHODOLITE CO.

Garnetiferous rock on Sugar Loaf Mountain, 2½ miles south of Willits, N. C., is being developed by the Rhodolite Co. In March, 1925, a new mill for treating the ores was nearing completion, and preparations were being made to start quarrying. The deposit has yielded a considerable tonnage of garnet by work done at intervals during the past 25 years, but this is the first attempt to recover the garnet by systematic large-scale operations.

The garnet occurs in small crystals, one-eighth to one-half inch in diameter, in mica and quartz-feldspar schists of unknown extent. The average garnet content of the rock is 20 to 25 per cent; local concentrations are as high as 60 per cent. Unlike the garnet of New York and New Hampshire, this garnet is rose colored and seems more closely related to rhodolite than to any other variety. The principal gangue minerals are biotite, feldspar, quartz, and pyrite.

The quarry and mill are in a narrow valley at the base of the mountain whose sides rise steeply. The overburden, a mixture of soil and boulders, ranges from a few inches to 4 feet in depth. The present quarry, about a hundred yards up the valley from the mill, has been developed enough to disclose a considerable tonnage of garnet ore. The track grade is such that ore can be transported to the mill in 1-ton cars by gravity. Plans for the mill contemplate dry concentration according to the flow sheet shown in Figure 3. Some small changes in the mill and more equipment to increase the capacity may prove necessary after the mill is in operation. A 24 by 15 inch jaw crusher set at 3.5 inches will crush the ore and will be followed by a gyratory crusher set to 0.75 inch.

The crushed ore will go directly to a drier or be by-passed by a conveyor and elevator to a set of screens. Oversize from the quarter-inch and 12-inch mesh screens will go to two sets of rolls, one to crush to three-eighths inch and the other to 10 mesh. The crushed garnet from these rolls is to be returned to the elevator and re-
Figure 3.—Flow sheet of mill of the Rhodolite Co.
screened. The final products will be sized as follows: 10 to 18 mesh, 18 to 30 mesh, 30 to 50 mesh, 50 to 90 mesh, minus 90 mesh. Each size will be stored in a 50-ton bin.

As the garnet does not tend to break into extremely fine particles, the minus 90-mesh material will be sent directly to waste, because it does not contain enough garnet to make recovery profitable. The sized products will be concentrated alternately on dry tables. The concentrates may be bagged and shipped directly as run-of-mill garnet or sent to an electrostatic machine that will remove any pyrite and biotite present. Separation of the minerals with this machine is greatly increased by heating the charge, which will, therefore, be warmed by steam pipes to 125°F. The clean concentrate from the electrostatic machine may be bagged for shipment or sent to a set of rolls, crushed, and graded into the final sizes by a set of screens. The run-of-mill material from the dry tables may also go to a Hardinge mill in closed circuit with an air separator that will prepare a 200-mesh powder suitable for grinding plate glass. If desired, a clean biotite concentrate may be prepared as a by-product. This type of mica is suitable for concrete facing, rolled roofing, and the manufacturer of ornamental powders. Two 130-horsepower Diesel-type engines with a generator directly connected will provide power for the mill. It is estimated that the mill will produce 12 tons of concentrates per 10-hour shift from ore containing 20 to 25 per cent garnet.

**Other Deposits**

Deposits of garnet-bearing rocks are abundant in western North Carolina and a small, irregular production has been reported from several localities. A large deposit of garnetiferous hornblende-gneiss which outcrops near Shooting Creek in Clay County contains almandite garnet in small crystals seldom exceeding three-fourths inch in diameter. A black garnet found in this locality is said to be suitable for abrasives. It is apparently a red almandite containing minute inclusions of black minerals which make it look black on casual examination. A considerable area of the hornblende-gneiss is exposed on Penland Bald Mountain a few miles from Shooting Creek; it shows garnet in amounts ranging from 2 to 15 per cent. A considerable tonnage of ore that would furnish mill rock containing 5 to 6 per cent of garnet is available. The garnet has the laminated structure typical of almandite and yields very sharp abrasive grains. Absence of good roads and the distance to railroad transportation have prevented the development of these deposits on a commercial scale. As the total amount of garnet-bearing
rocks is enormous the district may become an important source of abrasives in the distant future.

Large amounts of almandite garnet suitable for making abrasives occur in the district northwest of Marshall in Madison County. The garnet is present as crystals one-quarter to 1 inch in diameter in a mica schist and the deposits have potential commercial importance.

DEPOSITS IN OTHER STATES

Deposits of garnetiferous rock from which a supply of the mineral suitable for the abrasive market may be obtained are known to occur in Georgia, Virginia, Montana, Colorado, and many western States. The ore reserves of the active producers are large enough to supply the market at the present rate of consumption for many years.

DEPOSITS IN FOREIGN COUNTRIES

Although many deposits of garnet occur outside of the United States, little has been done toward their development. The foreign demand for garnet abrasives has been small and the requirements of the American market could be met most of the time by domestic producers.

SPAIN

For a time some abrasive garnet was produced in the Province of Almeria, Spain, where the garnet occurs in small rounded crystals associated with sand and gravel in stream deposits. This garnet is considered inferior to the standard American article, as it does not make as hard and sharp an abrasive and the small size of the crystals increases the difficulty of obtaining the full range of sizes required for the manufacture of abrasive papers. In the early years of the garnet industry, when the domestic supply was not equal to the demand, imports of Spanish garnet ranged from 500 to a maximum of 3,000 tons annually. In 1924 the imports dropped to approximately 300 tons and at present the domestic production exceeds the demand.

CANADA

Many deposits of garnet have been reported in Canada, some of which could supply a large tonnage of mineral suitable for use as an abrasive. The most important are at Depot Harbor on Parry Island, and in the townships of Ashby, Elzevir, Portland, Loughrin, Dill, and Harcourt in Ontario; at Chegoggin Point, Yarmouth, Nova
Scotia; and in Rawdon and De Ramsey Townships, Quebec. Little commercial development has been done except at two localities.

A few tons of garnet ore have been mined at Depot Harbor, where prospecting disclosed an extensive ore body said to average 15 per cent garnet. Water transportation is available and the erection of a concentrating mill has been considered. The first appreciable output of Canadian garnet was in 1923, when one producer, the Bancroft Mines Syndicate, shipped 1,250 tons of hand-picked ore and concentrates, valued at $100,000, to abrasive paper manufacturers in the United States. The Bancroft Mines Syndicate worked a deposit on Concession 19, lot 9, Ashby Township, Ontario. The garnet (almandite) occurs in small crystals from one-fourth inch to 1 inch in diameter in a hornblende-biotite gneiss and constitutes 25 to 40 per cent of the whole rock mass. An average mill feed of 30 per cent garnet was obtained. The deposit is on a hillside thickly covered with brush and a light overburden of soil, and its extent has not been accurately determined. The quarry has been carried 40 feet into the hillside, leaving a face 20 feet high. Stripping for 150 feet along the strike disclosed uniform ore. The deposit is 15 miles from Bessemer siding, the railroad shipping point. A new road may shorten the wagon haul. The concentrator burned down in the fall of 1923 and little mining has been done since.

INDIA

Garnet is abundant in many of the gneisses and schists of the Indian peninsula and the garnet liberated by disintegration of these rocks has been concentrated in river and sea sands. Gem garnet has been produced in India for centuries and its collection, cutting, and polishing forms a small local industry. Garnetiferous gneisses are common in Orissa and attempts have been made to market a massive garnet rock from the Hazaribagh district. Some garnet recovered from the river sands of the Nellore district has been sold for use as an abrasive. Deposits of garnet, believed to be suitable for abrasive manufacture, are widely distributed in Mysore. The garnet occurs in mica and hornblende schists and gneisses and also as fragments of crystals in stream sands and in the soil. According to a Government report in 1914, more than 1,000 tons of garnet sand for abrasive purposes were collected in the Tinnevelly district of Madras. The Indian production from 1914 to 1919 is reported as follows:

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7 Garnet: Bull. Indian Industries and Labours, No. 12, Calcutta, 1921, pp. 49-54.
### Production of garnet in India

<table>
<thead>
<tr>
<th>Year</th>
<th>Garnet sand (hundredweight)</th>
<th>Value (pounds sterling)</th>
<th>Year</th>
<th>Garnet sand (hundredweight)</th>
<th>Value (pounds sterling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1914</td>
<td>21,440</td>
<td>464</td>
<td>1917</td>
<td>nil</td>
<td>NIL</td>
</tr>
<tr>
<td>1915</td>
<td>115</td>
<td>374</td>
<td>1918</td>
<td>nil</td>
<td>NIL</td>
</tr>
<tr>
<td>1916</td>
<td>470</td>
<td>1,045</td>
<td>1919</td>
<td>1,045</td>
<td></td>
</tr>
</tbody>
</table>

1 From Tinnevelly district, Madras.
2 From Hyderabad (Deccan), mainly.
3 From Mysore.

Some abrasive garnet has been exported to Great Britain and Europe, but the business was abandoned as unprofitable. The plentiful supply of cheap labor in India should make the cost of production low. The information available does not indicate that Indian garnet is equal to the American article and can compete with it in the manufacture of high-grade abrasives.

### NYASALAND

In 1924 samples of a coarsely crystalline garnet from Malawe Hill, Nyasaland, were submitted to manufacturers of abrasives. This garnet was said to be of good quality and suitable for use as an abrasive. Little is known of the extent of the deposit from which the samples were taken or the possibility of producing garnet on a commercial scale.

### PRODUCTION OF ABRASIVE GARNET

The production of abrasive garnet in the United States did not attain commercial importance until the North River Garnet Co. began milling in 1893. Since then, except in periods of business depression, the production has indicated a constant annual increase in demand. The table below gives the production of crude garnet in short tons and the value in dollars for the years 1895 to 1924.

#### Production of abrasive garnet in the United States, 1895-1924

<table>
<thead>
<tr>
<th>Year</th>
<th>Short tons</th>
<th>Value</th>
<th>Year</th>
<th>Short tons</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895</td>
<td>3,325</td>
<td>$95,000</td>
<td>1910</td>
<td>3,814</td>
<td>$113,574</td>
</tr>
<tr>
<td>1896</td>
<td>2,588</td>
<td>68,877</td>
<td>1911</td>
<td>4,076</td>
<td>121,748</td>
</tr>
<tr>
<td>1897</td>
<td>2,534</td>
<td>80,835</td>
<td>1912</td>
<td>4,917</td>
<td>163,277</td>
</tr>
<tr>
<td>1898</td>
<td>2,967</td>
<td>86,820</td>
<td>1913</td>
<td>5,308</td>
<td>183,422</td>
</tr>
<tr>
<td>1899</td>
<td>2,735</td>
<td>98,325</td>
<td>1914</td>
<td>4,231</td>
<td>145,510</td>
</tr>
<tr>
<td>1900</td>
<td>3,185</td>
<td>123,475</td>
<td>1915</td>
<td>4,301</td>
<td>139,584</td>
</tr>
<tr>
<td>1901</td>
<td>4,444</td>
<td>158,100</td>
<td>1916</td>
<td>6,171</td>
<td>208,850</td>
</tr>
<tr>
<td>1902</td>
<td>3,028</td>
<td>132,520</td>
<td>1917</td>
<td>4,995</td>
<td>198,327</td>
</tr>
<tr>
<td>1903</td>
<td>3,930</td>
<td>132,500</td>
<td>1918</td>
<td>4,690</td>
<td>248,161</td>
</tr>
<tr>
<td>1904</td>
<td>3,854</td>
<td>117,581</td>
<td>1919</td>
<td>4,944</td>
<td>310,131</td>
</tr>
<tr>
<td>1905</td>
<td>5,059</td>
<td>148,065</td>
<td>1920</td>
<td>5,476</td>
<td>344,425</td>
</tr>
<tr>
<td>1906</td>
<td>4,650</td>
<td>155,690</td>
<td>1921</td>
<td>3,048</td>
<td>260,057</td>
</tr>
<tr>
<td>1907</td>
<td>7,058</td>
<td>211,866</td>
<td>1922</td>
<td>7,054</td>
<td>568,579</td>
</tr>
<tr>
<td>1908</td>
<td>1,996</td>
<td>64,620</td>
<td>1923</td>
<td>9,006</td>
<td>688,437</td>
</tr>
<tr>
<td>1909</td>
<td>2,972</td>
<td>102,315</td>
<td>1924</td>
<td>8,290</td>
<td>674,176</td>
</tr>
</tbody>
</table>

MARKETING OF ABRASIVE GARNET

Producers of abrasive garnet customarily ship their product as an unsized concentrate—a mixture of the different sizes of grains produced in milling. A small amount of hand-cobbled ore consisting of irregular fragments of garnet crystals, few exceeding 2 or 3 inches in diameter, is also shipped. The manufacturers of garnet abrasives crush and grade these products to the different sizes necessary for making the finished abrasives. The crude garnet is generally shipped in 100-pound bags and is quoted at a price per net ton f. o. b. shipping point. No extra charge is made for bags. In March, 1925, quotations were as follows: Domestic Adirondack, $85 f. o. b. shipping point; Spanish, $60 c. i. f. port of entry; Canadian, $70 to $80 f. o. b. mines. There is a tendency among producers of garnet to install grading equipment at their mills, and in the future it is likely that the consumers will be able to buy any desired size directly from producers.

To meet the demand of plate-glass makers for a fine grinding powder several producers of garnet have added suitable grinding equipment to their mills. Sized garnet grain is sold by the pound, the price depending on the quality of garnet and the size of grain.

MANUFACTURE OF GARNET ABRASIVES

Over 90 per cent of the garnet produced is made into surface-coated abrasives; the remainder is sold as loose grains or powders used in special grinding and polishing operations.

CRUSHING AND SIZING

The first step in the manufacture of garnet abrasives is to crush and accurately size the crude garnet or concentrate received from the mill operator. Here the tendency of garnet to include other minerals within its crystals becomes evident. In some varieties of garnet this tendency is so strong that the garnet has to be cleaned after each crushing to free it from the foreign minerals liberated. This cleaning is accomplished by reconcentration on a dry table. At some plants it is customary to reconcentrate all garnet concentrates in order to prepare a secondary concentrate of the highest possible purity. Biotite and hornblende, the minerals most commonly associated with garnet, are black, and, although their presence in small amounts does not detract appreciably from the value of an abrasive, their appearance is objectionable, and therefore efforts are made to eliminate them.

The cleaned garnet concentrate is crushed in rolls and screened to different sizes. The grade numbers ordinarily used to indicate the size of garnet range from 20 mesh, known as No. 3½, through Nos. 8, 2½, 2, 1½, 1, ½, 1/0, 2/0, 3/0, 4/0, 5/0, 6/0, and 7/0, which is 220 mesh. A coarser product, Nos. 4 and 5, is prepared by some
companies. The accompanying table from a Bureau of Mines report indicates the screen mesh corresponding to the grade number of abrasive garnet and of other common abrasives. In grading garnet extremely accurate sizing within narrow limits is demanded. The

Comparative sizes of abrasive grains

[Figures in columns represent grit numbers commonly used]

<table>
<thead>
<tr>
<th>Standard screen mesh</th>
<th>Standard size of opening (inches)</th>
<th>Flint paper and cloth</th>
<th>Garnet paper and cloth</th>
<th>Silicon carbide and artificial corundum</th>
<th>Emery and artificial corundum paper and cloth</th>
<th>Silicon carbide and artificial corundum paper disks</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>.0029</td>
<td></td>
<td>7/0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>.0033</td>
<td></td>
<td>6/0</td>
<td>220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>.0038</td>
<td></td>
<td>5/0</td>
<td>200</td>
<td>3/0</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>.0042</td>
<td></td>
<td>4/0</td>
<td>180</td>
<td></td>
<td>2/0</td>
</tr>
<tr>
<td>120</td>
<td>.0046</td>
<td></td>
<td>3/0</td>
<td>150</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>100</td>
<td>.0055</td>
<td></td>
<td>2/0</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>90</td>
<td>.0059</td>
<td>1/4</td>
<td>1/4</td>
<td>90</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>80</td>
<td>.0068</td>
<td></td>
<td>0</td>
<td>80</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>70</td>
<td>.0073</td>
<td></td>
<td>1/2</td>
<td>70</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>60</td>
<td>.0079</td>
<td>1/2</td>
<td>1/2</td>
<td>60</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>.0101</td>
<td></td>
<td>1/4</td>
<td>50</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>.0140</td>
<td>2/4</td>
<td>2/4</td>
<td>40</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>30</td>
<td>.0198</td>
<td>3/4</td>
<td>3/4</td>
<td>36</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>.0340</td>
<td></td>
<td>3/4</td>
<td>24</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>15</td>
<td>.0468</td>
<td></td>
<td>4/4</td>
<td>24</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>.0650</td>
<td></td>
<td>5/4</td>
<td>12</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

1 In this table the size of grain as related to screen mesh is indicated by the position of the dots between the horizontal lines. Thus, No. 2 1/4 garnet is about 28 mesh.

next coarser number permissible in any one grade is only 5 per cent. Standard grades have been adopted by the American Surface Abrasive Manufacturers, so that the consumer may purchase standardized abrasives from different manufacturers and utilize them with no change or interruption in his operations.

Garnet is screened in a series of slightly inclined, rectangular, vibrating frames covered with wire screen-cloth or silk grit gauze. Wire screens are more commonly employed for the coarse sizes and silk gauze for the finer. The silk gauze, which can be obtained in accurate mesh, displays a surprising resistance to the abrasion of a mineral so hard and sharp as garnet. The openings enlarge through wear and the screened products must be constantly tested to insure accurate sizing. The under size from the various screens falls into small bins provided with discharge gates.

COATING THE CLOTH OR PAPER BACKING

Paper or cloth or, sometimes, a combination of the two is coated with this closely sized garnet. Manila fiber, or rope paper, is used for the best quality of garnet papers, and Kraft paper for the cheaper grades. The cloth backings comprise various weights of drills, jeans, or twills. Large rolls of these backings pass continuously through a rotary press which prints the manufacturers' name and the size of the abrasive at regular intervals on the reverse side. Then the backing passes between two rolls, one of which revolves in a trough of glue and spreads a film of the adhesive over the surface, and then passes beneath a hopper from which a shower of sized garnet grains descends upon the glued surface. The excess garnet is shaken off and the cloth or paper is suspended in great loops upon drying racks.

The machinery for handling paper backings is similar to that employed in the manufacture of wall paper. After drying, a second, or "sizing," coat of glue is run over the garnet-coated surface to anchor the grains firmly in place. The best quality of hide glue is employed to coat the paper and anchor the grains. After the garnet paper has dried it is wound in large rolls which later are cut into standard-size sheets (9 by 11 inches) or are fabricated into 50-yard rolls of varying widths or into belts or disks suitable for the various demands of industry.

On a new type, nonclogging, abrasive paper, the garnet grains are scattered by mechanical means so that there is a small space between each grain and those surrounding it. This paper is particularly useful in abrading gummy materials, such as resinous woods, which tend to clog the regular paper by filling the spaces between the closely crowded grains, thereby greatly lessening their abrasive value. Special waterproof sheet abrasives are prepared for certain classes of work which can be done more efficiently when the materials are wet. In the manufacture of these abrasives an adhesive insoluble in water replaces glue.
To produce a satisfactory abrasive requires constant attention and the processes are regulated by laboratory control; the size of the garnet grains, the viscosity of the glue, and the quality of all the raw and finished products are examined repeatedly.

In the manufacture of abrasive papers the cost of the garnet represents 16 to 20 per cent of the total cost; the other items are labor, paper, and glue. The amount of garnet per unit of area depends upon the size of grain, character of backing, strength of glue, and type of paper; nondoiling papers contain less garnet than those that are completely covered with the abrasive.

**Superiority of Garnet Paper to Sandpaper**

Considerable difference of opinion exists concerning the conditions in which the superiority of garnet paper over quartz sandpaper is most marked. For many kinds of work it is universally conceded that the use of garnet paper is more economical than quartz or sandpaper, although its initial cost is greater. In abrading soft, resinous woods garnet and sand papers appear to be nearly equal in efficiency, as both are soon clogged with the abraded particles of wood and the cutting edges so blinded that the paper must be discarded. In working hardwoods and similar substances the superiority of garnet over quartz becomes most pronounced. Reports concerning the effectiveness of garnet on hardwoods vary with local conditions, but indicate that garnet will cut from two to six times as much wood as quartz whether measured by weight or the area of the surface abraded. Garnet does not have enough hardness to abrade the harder metals, but can be used satisfactorily on many of the softer ones, including copper, brass, and bronze. Garnet cuts leather rapidly and evenly.

The bulk of the garnet-coated abrasives is made up into belts, covers for drum sanders, or disks. Belts and drum sanders are driven at high rates of speed, varying from 1,000 to 3,000 feet per minute. A considerable percentage of sheet goods is also consumed by hand use.

A multitude of industries, particularly woodworking, metal working, and leather working, use abrasive garnet.

**Uses of Garnet Paper**

**Woodworking**

Garnet paper is employed in woodworking wherever a smooth, natural finish or a prepared surface for varnish or shellac is desired. It is most valuable in the finishing of the highest class of furniture, such as pianos, phonograph and radio cabinets, and home and office
furniture. Manufacture of one piano case is said to require about 25 square feet of garnet paper. The finishing of the woodwork necessary for the manufacture of wagons, carriages, automobiles, boats, and railroad cars, also uses much garnet paper, as does the smoothing of wheels, spokes, handles for all types of tools, hardwood floors, sash, doors, blinds, and all kinds of millwork. In fact, garnet paper is of value in nearly every woodworking operation where a smooth surface is desired.

**METAL WORKING**

Garnet paper for metal working is sold to manufacturers of various machines, automobiles, electric appliances, brass specialties, and metal furniture, who use it for cleaning castings, grinding valves, and finishing surfaces.

**LEATHER WORKING**

In the manufacture of boots and shoes garnet paper is used for scouring heels and soles. It is also used in repair shops for finishing the heels and soles to final size and smoothing their edges.

**SPECIAL USES**

Garnet paper has various special uses. It is employed to finish rubber, bakelite, and celluloid in much the same manner as in finishing hardwoods. It has been used as an abrasive in cleaning hardwood and composition floors and other materials by vigorous scouring. The fine papers are used in finishing felt and silk hats, and also in dental work. In the weaving of silk, rolls covered with garnet paper are used to draw the fabric from the loom. Garnet paper is commonly used to remove and rub down paint and varnish on both wood and metal surfaces.

Loose garnet grain for special uses is also sold by the manufacturers of abrasive papers. In some industries special belts and abrasive shapes have to be made for unusual work that can not be done with the ordinary garnet products. These special abrasives are prepared by attaching the garnet grains with a suitable adhesive to belts or shapes prepared for the particular requirements. A small amount of garnet grain is bonded into wheels which have a limited use in the grinding of glass and metals. The low fusion point of garnet and its susceptibility to alteration by heat make impossible the use of any ceramic bond that would require firing in a kiln. These wheels are bonded with sodium silicate, rubber, shellac, or similar organic substances.

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GLASS POLISHING

Since the introduction in 1914 of garnet as an abrasive for the grinding of plate glass the demand for this purpose has gradually but constantly increased. As the garnet is used for the finest grinding, it must be prepared as a fine powder, ranging from 200 to 325 mesh. The molten glass is rolled into sheets about one-half inch thick and after annealing is set in plaster of Paris on round steel tables from 24 to 36 feet in diameter which have been machined to perfectly plane surfaces. A table bearing a glass sheet is put under a grinding machine which consists of a revolving spindle that carries and turns the table, glass and all. Two freely revolving iron-shod rollers are suspended above the table; one extends over the center of the table, and the other covers the rest of the diameter. When the table is revolving the rollers are lowered, sand and water are applied between the iron of the rollers and the glass surface, and grinding continues until the glass has a plane surface. The sand must pass a 16 to 20 mesh screen and should not contain any material fine enough to pass 50 mesh. To fine the surface of the glass the grinding is continued with garnet until a satisfactory surface is produced. Then the glass is polished in a similar machine provided with felt-covered rolls using rouge as a polishing medium. After one side is finished the glass is turned over and the process repeated on the other side.

SPECIFICATIONS AND TESTS

There are no definite specifications for abrasive garnet. The only way in which the suitability of a specimen of garnet for abrasive purposes can be determined is by actual use and comparison with other garnet products of accepted value as abrasives. In general the suitability of garnet for use as an abrasive depends on its hardness, toughness, fracture, purity, and the size of the crystals available. The mineral should have a hardness above 7.0 and should be tough enough to withstand considerable shock without shattering, but should break after long continued use and present a new cutting edge rather than wear down to a dull surface. The fracture should be such that sharp cutting edges are constantly produced. The tendency toward conchoidal fracture should not be strong enough to produce thin sharp flakes, which are undesirable.

Crude garnet or garnet concentrate carrying less than 90 per cent of the mineral would hardly be of commercial grade to-day, whereas in the early days of the garnet industry when methods of production were rough a material containing as low as 50 per cent garnet was utilized. The adoption of modern equipment and methods for the concentration of garnet has made possible the marketing of a purer product whose value has been appreciated by consumers. Garnet that occurs in small grains in rock or in loose sand is of inferior
value, because the crushed grains tend to have rounded faces and a full range of commercial sizes can not be obtained. Color is of no value as an indicator of abrasive qualities.

The determination of the hardness of any mineral is at best an inaccurate procedure. No method is known by which the hardness may be positively determined, and it is, therefore, necessary to resort to a scale by which the hardness of any mineral may be expressed in a relative manner. Moh’s scale consists of 10 common minerals arranged in order of increasing hardness. On this scale feldspar is 6, quartz 7, topaz 8, corundum 9, and diamond 10. Abrasive garnet scratches quartz, but in turn is scratched by topaz, and therefore possesses a hardness between these limits which is commonly expressed as 7.5. Some specimens of garnet sometimes appear to have a hardness closely approaching 8.

CHEMICAL ANALYSIS

Chemical analysis is of little value in determining the suitability of a garnet for use as an abrasive, because abrasiveness depends on physical properties. To obtain accurate information on the composition of any specimen of garnet the sample must be prepared with great care. All foreign minerals must be removed, and as these are often present in very small particles it becomes necessary to crush the garnet, examine the powder with a microscope, and remove all impurities. The separation of garnet from other minerals may sometimes be expedited by the use of heavy solutions. Samples from five of the most important commercial sources were analyzed. As analyses of samples taken from the same deposit often show considerable difference, the analyses below may not represent absolutely the garnet in the localities named, but are indicative of the general type of garnet.

The five samples represent the following localities: 1, Massive garnet from the Adirondacks, New York; 2, crystal garnet from the Adirondacks, New York; 3, “rhodolite” garnet from western North Carolina; 4, imported Spanish garnet; 5, New Hampshire garnet.

### Analyses of garnet

<table>
<thead>
<tr>
<th></th>
<th>1 Adiron-</th>
<th>2 Adiron-</th>
<th>3 North</th>
<th>4 Imported</th>
<th>5 New</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dack,</td>
<td>dack,</td>
<td>Carolina</td>
<td>Spanish</td>
<td>Hamp-</td>
</tr>
<tr>
<td></td>
<td>massive</td>
<td>crystal</td>
<td></td>
<td></td>
<td>shire</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>38.92</td>
<td>40.24</td>
<td>38.52</td>
<td>37.06</td>
<td>37.39</td>
</tr>
<tr>
<td>Alumina (Al₂O₃)</td>
<td>22.77</td>
<td>20.06</td>
<td>21.53</td>
<td>26.92</td>
<td>20.46</td>
</tr>
<tr>
<td>Iron oxide (ferric) (Fe₂O₃)</td>
<td>1.80</td>
<td>4.65</td>
<td>2.72</td>
<td>6.00</td>
<td>2.89</td>
</tr>
<tr>
<td>Iron oxide (ferrous) (FeO)</td>
<td>23.34</td>
<td>18.58</td>
<td>27.75</td>
<td>32.24</td>
<td>31.87</td>
</tr>
<tr>
<td>Calcium oxide (CaO)</td>
<td>5.22</td>
<td>5.34</td>
<td>2.03</td>
<td>1.02</td>
<td>.92</td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>7.09</td>
<td>11.18</td>
<td>8.28</td>
<td>1.86</td>
<td>2.46</td>
</tr>
<tr>
<td>Manganese (MnO)</td>
<td>.15</td>
<td>.25</td>
<td>.12</td>
<td>2.93</td>
<td>3.47</td>
</tr>
<tr>
<td>Total</td>
<td>99.29</td>
<td>100.30</td>
<td>100.95</td>
<td>102.03</td>
<td>99.46</td>
</tr>
</tbody>
</table>

1 Analyses by E. E. Berger.  
2 Analyses by M. Farnsworth.
FUTURE DEVELOPMENT OF THE INDUSTRY

TEST OF ABRASIVENESS

To test the efficiency of abrasive garnet in the form of loose grain is difficult and unsatisfactory, therefore testing is done after the sized grain has been fixed to the cloth or paper backing. The usual test is abrading a standard wooden block for a given length of time and determining the amount of material removed. The test procedure differs. The paper may be made up into an endless belt or a disk, or applied to a small drum sander. To obtain uniform material the blocks of wood are cut from one plank. Some operators prefer to use one block of wood and change the abrasive working on it in order to be assured of identical conditions. The test commonly lasts 10 minutes and the amount of wood abraded in this time is determined by weighing or the loss may be determined every minute and the results plotted in a curve. A standard abrasive paper of known efficiency is used as an index and the results of an unknown paper are reported as a percentage of this standard.

FUTURE DEVELOPMENT OF THE INDUSTRY

The present condition of the industry indicates that the utilization of garnet may be expected to increase. In the year 1924 the industry made its greatest expansion with the erection of new mills in New York and North Carolina. The potential output of the mills now in construction may be estimated to be in excess of 20,000 tons annually. As the annual consumption in 1924 was about 9,000 tons, it is natural to expect that attempts will be made to broaden the market and find an outlet for the excess production.

Some of the present markets for garnet can be expanded considerably. The use of garnet in the plate-glass industry is limited. If the practice of fine grinding with garnet should become universal in the plate-glass industry an additional demand for several thousand tons annually is possible. The use of abrasive garnet is peculiarly American and as its use in other countries is small the export business has been practically negligible. The introduction of garnet products into the industries of foreign countries, particularly the wood, metal, and leather working trades of Europe, should provide an outlet for a considerable tonnage.

The possibility of finding new uses for garnet has been the subject of some investigation. Garnet grains have been used for facing tile and concrete block; besides being ornamental the garnet presents a surface having great resistance to wear. Substitution of garnet sand for quartz sand in sand blasting has been advocated, but garnet costs considerably more than quartz sand; and hence could be used only where its superior abrasive qualities are of value and the used grain can be recovered.
A possibly large market exists in the surfacing and polishing of the softer ornamental stones, such as marble, slate and serpentine. Large amounts of these stones are cut annually into thin slabs which are used for floors, wall panels, and architectural work. The blocks of stone are sawed into slabs with gang saws—strips of steel fed with sand. The actual cutting is done by the sand being dragged against the marble surface by the steel blade. According to Sewell, if an abrasive could be made available that would cut three or more times as fast as sand, and not cost more than 10 times as much per ton—or if its lasting qualities were proportional to its higher price if it were very expensive—the cutting of marble would be greatly facilitated. The possibility of garnet meeting these requirements will have to be determined by actual use.

Plate III shows the shape of the grains in crushed garnet.

MILLING OF GARNET

The chief factors that control the behavior of garnet during concentration are the identity and characteristics of the associated minerals, the size of the garnet crystals, and the percentage of them in the ore. The common associates of garnet are feldspar, mica, hornblende, pyroxene, and quartz. Magnetite, pyrite, ilmenite, limonite, pyrrhotite, and occasionally chalcopyrite, rutile, zoisite, and corundum are associated in much smaller percentages. The sodium feldspar, plagioclase, is a more common associate of garnet than the potash-bearing varieties. Biotite, the black iron-bearing mica, is seen more often than muscovite, the white mica. Hypersthene and diopside are the most common varieties of pyroxene. The most important characteristic controlling the behavior of these minerals during concentration is specific gravity.

SPECIFIC GRAVITY OF GARNET AND OF ASSOCIATED MINERALS

The authors determined the specific gravity of a large number of mineral specimens from two of the most important deposits actively worked in the Adirondack region of New York State. These specimens, here classified as clean garnet, clean hornblende, locked garnet, and common gangue, were collected from the feed, concentrate, and tailings of the mills, and from representative localities in the quarries. The clean garnet represents selected specimens in which no foreign minerals were visible, and the clean hornblende represents similarly selected specimens. The locked garnet represents specimens in which the garnet in varying amounts is attached to the gangue minerals. The common gangue is the mixture of minerals that composes the rock surrounding the garnet.

The mineralization of these deposits is comparatively simple. In addition to garnet the rocks are composed essentially of feldspar, hornblende (occasionally present in pure, fairly large masses), pyroxene, and a little biotite. These minerals form about 98 per cent of the rocks which are fairly fine textured. Magnetite, pyrite, and ilmenite are disseminated in such small particles that they have little effect on the specific gravity of the rock.

**Specific gravity of garnet, hornblende, and gangue**

<table>
<thead>
<tr>
<th>Specimens from Deposit 1</th>
<th>Maximum specific gravity</th>
<th>Minimum specific gravity</th>
<th>Average of all determinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean garnet</td>
<td>4.11</td>
<td>3.88</td>
<td>3.95</td>
</tr>
<tr>
<td>Clean hornblende</td>
<td>3.24</td>
<td>3.07</td>
<td>3.16</td>
</tr>
<tr>
<td>Locked garnet</td>
<td>3.09</td>
<td>3.31</td>
<td>3.10</td>
</tr>
<tr>
<td>Common gangue</td>
<td>3.18</td>
<td>2.96</td>
<td>3.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimens from Deposit 2</th>
<th>Maximum specific gravity</th>
<th>Minimum specific gravity</th>
<th>Average of all determinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean garnet</td>
<td>4.19</td>
<td>3.90</td>
<td>4.00</td>
</tr>
<tr>
<td>Clean hornblende</td>
<td>3.19</td>
<td>3.10</td>
<td>3.16</td>
</tr>
<tr>
<td>Locked garnet</td>
<td>3.44</td>
<td>3.00</td>
<td>3.23</td>
</tr>
<tr>
<td>Common gangue</td>
<td>2.95</td>
<td>2.65</td>
<td>2.79</td>
</tr>
</tbody>
</table>

The specific gravity of the clean hornblende is of interest because of the common reports that the gravity of the hornblende and garnet lie so close together that separation of the two minerals by gravity concentration is very difficult. The specific gravity of the locked garnet has a considerable range, as might be expected. Garnet usually tends to break clean from the surrounding minerals when they are crushed, but these minerals sometimes adhere more strongly and the crushed ore contains fragments in which the garnet is fast to the gangue. These fragments are most conspicuous after the primary crushing. The secondary crushing is so regulated as to free the garnet completely.

Biotite and muscovite mica and quartz are not commonly associated with garnet in the Adirondack district but may be in other localities. The table below gives the specific gravity of the common accessory minerals:

**Specific gravity of minerals associated with garnet**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotite</td>
<td>2.70–3.20</td>
</tr>
<tr>
<td>Muscovite</td>
<td>2.80–3.10</td>
</tr>
<tr>
<td>Quartz</td>
<td>2.65</td>
</tr>
<tr>
<td>Feldspar</td>
<td>2.60–2.76</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>3.20–3.60</td>
</tr>
<tr>
<td>Rutile</td>
<td>4.20–4.30</td>
</tr>
<tr>
<td>Corundum</td>
<td>3.90–4.10</td>
</tr>
<tr>
<td>Limonite</td>
<td>3.40–4.00</td>
</tr>
<tr>
<td>Magnetite</td>
<td>4.90–5.20</td>
</tr>
<tr>
<td>Pyrite</td>
<td>4.90–5.20</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>4.50–4.60</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>4.10–4.30</td>
</tr>
</tbody>
</table>
Presence or absence of accessory minerals has little effect on the main operations in the concentration of garnet but may necessitate adjustments of minor details. The larger the garnet crystals the greater the proportion of clean garnet liberated on primary crushing. The tendency of garnet to include other minerals gives trouble because these minerals are often disseminated throughout the garnet crystals in such small particles as to require very fine crushing to insure a clean garnet product.

The percentage of garnet in commercial ores, as indicated in the discussion of milling operations, varies greatly—from a minimum of 6 per cent to a maximum of 60 per cent. The necessity of adjusting the flow sheet of any mill to the richness of the feed is evident.

**ASSAY OF GARNET ORES**

**MICROSCOPIC EXAMINATION**

Examination of mill products shows at once that a method of analysis by which the proportion of garnet can be determined accurately will be a great aid. The determination of garnet is a difficult operation and one which does not permit a high degree of accuracy. Because of the complex composition of garnet and the minerals with which it is commonly associated the proportion of garnet can not be determined by chemical analysis, and resort to mechanical means is necessary. Before the garnet can be separated from the associated minerals the ore must be crushed finely enough to liberate the garnet. Then a weighed portion of the crushed ore may be picked by hand with the aid of a small pair of tweezers and a magnifying glass, and the collected particles of garnet weighed, and the garnet content of the ore or mill product calculated. This method is laborious, and careful manipulation is necessary to get accurate results.

**USE OF HEAVY SOLUTIONS**

The assay of garnet ores may be facilitated by the use of heavy solutions. Although the specific gravity of the garnet group ranges from 3.4 to 4.3, the varieties of garnet of industrial importance have much closer limits, generally from 3.9 to 4. Except in isolated cases of unusual mineralization the gravity of the associated minerals does not exceed 3.20. It is obvious that the gangue minerals would float on a liquid having a specific gravity between 3.20 and 3.90, although the garnet would sink. With the aid of such liquids the garnet content of a sample of crushed ore may be determined.

Few liquids are suitable. One of the most convenient is methylene iodide, which has a gravity of 3.3. It is miscible in all proportions with benzol, gravity 0.88, and thus liquids of lower gravity can be prepared. Klein's solution (specific gravity 3.28), a solution of
cadmium boro-tungstate in water, may also be employed. As the preparation of heavy solutions is rather costly, their use has been limited. Accurate methods of sampling and assay have seldom been employed in the garnet industry. The garnet content of a deposit has been determined either by the estimate, based on careful examination, of an experienced man or by milling and concentrating a small experimental tonnage. The development of cheaply prepared heavy solutions and a simple technique for their use would be of considerable value to the operator of a garnet mill by enabling him to assay the various products from the concentrating equipment and to check up the efficiency of the mill.

At its Mississippi Valley station the Bureau of Mines is attempting to develop various heavy solutions that will be suitable for such determinations as that of garnet in its ores. Chemical analyses are more or less valueless in determining the content of many non-metallic minerals in their ores, because many of the minerals have a complex composition, and usually every element they contain is present in some of the associated minerals. Thus an assay for iron in a garnet ore gives no accurate measure of the amount of garnet present because the associated hornblende, magnetite, and mica also contain iron. Resort may be had to physical analysis by the use of heavy solutions. Mineralogists and geologists have used these solutions for isolating and identifying minerals, but the metallurgist has been backward in adopting them for ore dressing. As most of the concentration processes depend primarily on specific gravity, physical fractionation by heavy solutions provides a most effective tool in dissecting the structure and character of an ore with respect to suitable methods of concentration. For any ore that is to be concentrated by methods depending on specific gravity, physical dissection by means of these solutions provides a most valuable means for determining the nature of the mineral which is not recoverable by a particular machine. The character and the nature of the mineral lost in any tailing should be accurately known (heavy solutions assist greatly in this determination) before the mill operator can intelligently decide whether this mineral is recoverable in its present condition.

HEAVY SOLUTIONS AVAILABLE

For the study of garnet ores several heavy solutions are available. For removing such minerals as quartz, feldspar, etc., acetylene tetrabromide, which when chemically pure has a specific gravity of about 2.95, can be used; it is liquid at room temperature and may be diluted with carbon tetrachloride, whose specific gravity is about 1.60. For isolating the hornblende and minerals of similar specific gravity the
product which sinks in the acetylene tetrabromide solution could be tested with a solution of tin tetrabromide (specific gravity 3.31 when the pure salt is melted), which gives a clear liquid when melted at 30° C., slightly above room temperature. It may be diluted with carbon tetrachloride to obtain lower specific gravities. If the sink product in the tin bromide is now subjected to an antimony tribromide solution (specific gravity 3.7, liquid at 94° C.), the float product will be particles composed of garnet locked to the associated minerals, such as hornblende, and the sink product will be primarily free grains of garnet with small amounts of such minerals as magnetite, ilmenite, rutile, etc. To separate these minerals from the garnet the sink product in the antimony bromide may be put in a solution of thallium-silver nitrate (specific gravity about 4.8). This substance, made from the nitrates of the two metals, melts in the range of 65° to 80° C., the melting point varying with the relative amounts of the two nitrates present, is miscible with water, and a liquid of practically any specific gravity between 1.0 and 4.8 may be obtained. Water solutions of this double nitrate might be used for all of the separations mentioned above, but the substance attacks sulphides liberation of metallic silver. For a discussion of various heavy solutions, see articles by Retgers.\textsuperscript{11}

\textbf{Suggested Procedure in Fractionation}

The above discussion indicates briefly how a physical fractionation of a garnet ore might be made. To determine the percentage of garnet the following procedure might be followed: Garnet like that in the New York deposits is practically free from all associated minerals at 35 mesh; furthermore, garnet slimes very little. The sample to be tested for garnet content could be crushed carefully through 35 mesh. Then 5 to 10 grams or even more of the crushed sample could be stirred gently in a beaker of water and the genuine mud or slime could be decanted off, because the presence of mud or genuine slime finer than 325 mesh gives trouble in a separation with heavy solutions. Next the sample should be dried thoroughly and tested with the antimony tribromide solution (specific gravity 3.7) or a water solution of thallium-silver nitrate of about the same gravity. The garnet and the small amounts of such minerals as magnetite, ilmenite, and rutile would sink. If more than very slight quantities of these minerals were present with the garnet, they might be separated by using a solution of thallium-silver nitrate of higher gravity. This procedure would give a fairly accurate determination

of the garnet content. Under any circumstances it is probable that the amount of garnet removed by the preliminary treatment to remove mud would be negligible. Various details must be perfected before such a method of physical analysis will rank in extreme accuracy with the methods of chemical analysis used for other minerals, but it will be an advance over the rule-of-thumb methods, in which one judges the garnet content by eye or by tedious hand sorting.

PRINCIPLES OF GARNET MILLING

The basic principles of milling garnet have been illustrated in the descriptions of plant operations. Mills may use wet or dry concentration.

WET MILLING

In wet milling the general procedure is to subject the ore to a primary crushing that liberates most of the garnet from the gangue minerals, screen the crushed material, and concentrate the coarse-size products on jigs which produce a concentrate, middling, and tailing. The concentrate and tailing may be withdrawn immediately from the mill circulation as finished products or a dirty concentrate may be made which must be cleaned by further concentration. The middling is sent to secondary crushers and broken again to liberate its garnet content. The crushed middling product rejoins the mill circulation and is sized and concentrated. The finely crushed ore that has been separated by the screens is treated on tables or by special machines that have been designed for this particular work.

DRY MILLING

In dry milling the ore passes through a primary crusheator that discharges into a direct-heat drier. The dried product is screened, the oversize crushed further, and returned to the screen. The undersize, which has been separated into fractions having the desired dimensions, is stored in bins. The sized products from these bins are concentrated on dry tables which make a concentrate, middling, and tailing. The concentrate and tailing are finished products, but the middling is returned to the mill circulation for further treatment.

It is obvious that the amount of crushing to be done by the primary crushers, the sizes of screens for sizing the ore, and the type of equipment for concentration all depend so largely on local conditions that no standard technic for the concentration of garnet has been established. The peculiarities in mineralization of each deposit must be studied and a concentrating process devised that
will recover the largest possible percentage of the garnet at the lowest possible cost.

**CLASSES OF ORE**

Garnet ores may be classified as of two types. In the first the garnet occurs in large crystals, but the percentage of garnet in the ore is comparatively small. A representative ore of this type would contain crystals having a diameter of three-fourths inch or more which would form 4 to 15 per cent of the total rock mass. This type of ore is characteristic of the Adirondack section of New York. In the second type the mineral occurs in small crystals, seldom exceeding three-eighths inch in diameter. In some localities these crystals occur in such profusion that the garnet content of the rock may be as great as 60 per cent. This type is characteristic of the garnet deposits of New Hampshire and North Carolina.

**COMMENTS ON CRUSHING PRACTICE**

To obtain some information concerning the behavior of garnet during concentration the authors studied the performance of one mill. This study furnished data from which generalized conclusions were drawn as follows:

The extent to which primary crushing should be carried before concentration is begun depends upon the size of the garnet crystals and the facility with which the garnet breaks from the other minerals. Rough concentration of some of the New York ores could begin on material as coarse as three-fourths inch, because many of the crystals are larger than this and preliminary crushing liberates much of the garnet. The ores of New Hampshire and North Carolina, in which the garnet crystals are much smaller, would require much finer crushing. Many engineers allow the consideration “At what size is the economic mineral completely free from gangue?” to govern the size at which concentration shall begin. The antithesis of this statement—that is, “When is a goodly portion of the gangue free from the economic minerals?”—is not often considered. The two principles may appear to have the same meaning, but they do not.

Often it may be found that at some particular size as much as 75 per cent of the gangue is barren of the economic mineral but only a small percentage of the economic mineral is free from gangue. Then an effort should certainly be made to begin concentration at that size, in order that as much of the barren gangue as possible be removed from the mill circulation and immediately sent to the tailing pile, thereby increasing the capacity of the mill and decreasing costs by the elimination of worthless material which no further treat-
ment can make of value. Such a consideration should govern the size of initial grinding at which concentration should begin. The primary concentration might not give a finished concentrate, but it should give a finished tailing whose production would be of most importance. Too much stress is often placed on getting a concentrate as quickly as possible, whereas the production of a “quick” tailing should be emphasized, especially if the gangue minerals comprise the bulk of the ore. Consideration should be given to the idea “Mill to produce finished tailing and the concentrate will take care of itself.”

The use of heavy solutions is a valuable aid in determining the point at which most of the gangue is free from the economic mineral. One can hardly expect to recover a clean concentrate while making a clean tailing, and the dirty concentrate made will require further treatment for separation into a clean concentrate and a middling. As this middling is the part of the ore in which the garnet and the gangue minerals are still mechanically locked, it will require further grinding. In most ores the garnet is not liberated completely until ground to about 35 mesh, and for some ores the grinding must continue to 90 mesh to permit the recovery of all the garnet.

If such coarse crushing as one-fourth inch to three-fours inch be practiced, to “bull-jig” at least the coarser part of the mill feed would be advisable as an attempt to remove as much tonnage as possible from the mill system by producing a clean tailing. The other products from the bull-jig would receive further treatment, such as regrinding and further concentration. The great advantage of removing as much tailing as possible in this first concentration is that a smaller tonnage has to be handled in subsequent milling. The tendency of laminated garnet to break in large flat flakes requires finer grinding than would be necessary otherwise as the large surface of these flakes prevents the garnet from sinking to the concentrate level in the jigs. Garnet in this form tends to float with the tailing and may be lost with it unless the crushing is fine enough to break down the flat particles. If much middling is produced in this first concentration especial care must be taken to provide effective devices and methods for recovering it; a fixed-sieve jig possibly has some advantage over a movable-sieve jig. Probably the best method is to try to draw these middlings at some level above the sieve level. This drawing is more difficult on a movable-sieve jig than on a fixed-sieve jig.

Fortunately, garnet does not slime during the crushing of the ore, consequently the treatment of slime, a serious problem in the milling of many zinc, lead, copper, and gold ores, does not have to
be considered. This absence of slime is also fortunate with respect to utilization, as the commercial demands are for comparatively coarse material. An accurate sample of the feed to one mill showed the following screen analysis:

**Screen analysis of mill feed**

<table>
<thead>
<tr>
<th>Screened product, size</th>
<th>Per cent by weight</th>
<th>Garnet content, per cent</th>
<th>Distribution of garnet, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(\frac{1}{4})-inch + ¼-inch</td>
<td>14.37</td>
<td>5.25</td>
<td>6.77</td>
</tr>
<tr>
<td>-(\frac{1}{4})-inch + ½-inch</td>
<td>12.81</td>
<td>6.60</td>
<td>7.59</td>
</tr>
<tr>
<td>-(\frac{1}{2})-inch + 1-inch</td>
<td>16.11</td>
<td>11.05</td>
<td>11.4</td>
</tr>
<tr>
<td>-¼-inch + 4-mesh</td>
<td>5.42</td>
<td>15.20</td>
<td>7.40</td>
</tr>
<tr>
<td>-4-mesh + 8-mesh</td>
<td>15.21</td>
<td>19.45</td>
<td>26.56</td>
</tr>
<tr>
<td>-8-mesh + 10-mesh</td>
<td>6.89</td>
<td>21.40</td>
<td>13.24</td>
</tr>
<tr>
<td>-10-mesh + 20-mesh</td>
<td>9.44</td>
<td>17.60</td>
<td>14.92</td>
</tr>
<tr>
<td>-20-mesh + 28-mesh</td>
<td>3.54</td>
<td>11.00</td>
<td>3.49</td>
</tr>
<tr>
<td>-28-mesh + 35-mesh</td>
<td>4.12</td>
<td>10.20</td>
<td>3.77</td>
</tr>
<tr>
<td>-35-mesh + 48-mesh</td>
<td>2.76</td>
<td>9.40</td>
<td>2.33</td>
</tr>
<tr>
<td>-48-mesh + 65-mesh</td>
<td>2.34</td>
<td>5.00</td>
<td>1.05</td>
</tr>
<tr>
<td>-65-mesh + 100-mesh</td>
<td>1.87</td>
<td>2.50</td>
<td>.42</td>
</tr>
<tr>
<td>-100-mesh + 150-mesh</td>
<td>1.36</td>
<td>2.00</td>
<td>.24</td>
</tr>
<tr>
<td>-150-mesh + 250-mesh</td>
<td>1.38</td>
<td>1.30</td>
<td>.16</td>
</tr>
<tr>
<td>-250-mesh + 325-mesh</td>
<td>.52</td>
<td>.60</td>
<td>.08</td>
</tr>
<tr>
<td>-325-mesh</td>
<td>1.86</td>
<td>.50</td>
<td>.08</td>
</tr>
<tr>
<td>Composite mill feed</td>
<td>100.0</td>
<td>11.14</td>
<td>100.00</td>
</tr>
</tbody>
</table>

The third column in the table gives the garnet content or assay as determined by hand sorting and weighing the products obtained or by microscopic count, and the fourth column indicates the percentage of the total garnet content in each size.

The quantity of garnet in material finer than 100 mesh in the mill feed is only 0.52 per cent of the total of all sizes. This figure—obtained by adding the percentages of garnet present in the sizes from minus 100 plus 150 mesh to minus 325 mesh in the column “Distribution of the garnet”—indicates that this material contains very little garnet fine enough to be considered slime. This mill feed had been prepared by crushing the run-of-mine rock from the quarry in a jaw crusher and screening in a three-fourth inch round-hole trommel. The oversize from the trommel was recrushed in a gyratory crusher and returned to the trommel for further screening, so that the entire mill feed was finally reduced to this size. Ores requiring a finer preliminary crushing would naturally contain larger quantities of fine garnet but it is improbable that any true slime would appear.

The middlings produced by the primary concentration must be crushed in order to free the locked garnet before concentration can be continued. If the mill feed were crushed initially through three-fourths inch and the portion between three-fourths inch and one-half inch were bull-jigged to remove some finished tailing, the middling concentrate from this operation should be crushed through one-half
inch and this material should be added to the minus one-half-inch portion of the original mill feed to give a product suitable for further concentration by jiggling.

Two procedures are open in jiggling. The feed may be screened and separated into sized fractions which are treated separately or the unsized material produced by crushing to a definite limit may be concentrated immediately without further sizing. Jiggling a sized feed is the method followed in the New York mills. The reason given for this sizing is that the specific gravities of the garnet and the associated hornblende are not far enough apart to enable a separation without sizing. But as already shown the difference in gravities is about 0.8 and it is not at all impossible that the jiggling of unsized feed as practiced in the Wisconsin and Tri-State zinc districts could be developed to the point where it would be successful with garnet ores. Flat flakes of laminated garnet might seriously interfere with jiggling an unsized feed but if this jiggling could be practiced it should appreciably decrease the cost of milling.

No definite limit may be established as to the size at which jiggling must stop and other methods be utilized to recover the fine material, but it is probable that anything finer than 2 millimeters should be concentrated on tables or special devices. In wet concentration accurate sizing before tabling is unnecessary although some simple classification should be practiced. Division into a “coarse-sand” product and a “fine-sand” product would probably suffice for satisfactory tabling. Because it contains no garnet, the extremely fine material could be sent directly to waste from the classifier. The heavy accessory minerals, such as pyrite, magnetite, and ilmenite, are in such small crystals that they are not liberated until crushed very fine, and commonly appear on the tables in a small streak above the garnet. It is probable that a moderate classification before tabling would largely eliminate these heavy minerals.

The concentration of garnet in dry mills on pneumatic tables leads either to a mill of small capacity or to a large investment. Wet milling is to be preferred because it is more efficient and economical. Dry milling relies on tables that have a capacity much less than the jigs of the wet mill. In a dry mill there can be little variety of treatment, as all the concentration must be done on one type of machine. The dust losses are high and the dust makes conditions unpleasant for the workmen and causes excessive wear of equipment.

A peculiar and local condition was noted in one garnet mill. Wet milling caused a reaction in the crushed ore whereby a reagent was produced which attacked the garnet. This reagent was believed to be sulphurous acid or ferric sulphate formed from the pyrite in the ore. Garnet concentrated by wet milling showed considerable de-
terioration after storage for a few weeks. Although this deterioration did not seriously injure the abrasive qualities of the garnet it caused a very objectionable appearance which impaired the value. Dry milling was therefore adopted.

There seems to be no reason why the methods ordinarily used for dressing metallic ores can not be applied in their entirety to such nonmetallic ores as those of garnet. Some garnet mills furnish good examples of such applications. It is to be expected that in future the technology of garnet will show greater refinements in concentration and a more economical recovery of the mineral.

MANUFACTURERS OF ABRASIVE GARNET PRODUCTS

The names and addresses of manufacturers of garnet products in the United States and Canada are listed below:

UNITED STATES

American Glue Co., East Walpole, Mass.
Armour Sandpaper Works, Chicago, Ill.
Herman Behr & Co. (Inc.), Brooklyn, N. Y.
The Carborundum Co., Niagara Falls, N. Y.
Manning Abrasive Co., Troy, N. Y.
Minnesota Mining & Manufacturing Co., St. Paul, Minn.
United States Sand Paper Co., Williamsport, Pa.
Wausau Abrasive Co., Wausau, Wis.

CANADA

Western Abrasives (Ltd.), Victoria, British Columbia.
Abrasive (Ltd.), Brantford, Ontario.
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Many references to the use of garnet as a semiprecious stone have been published; literature on its far more important use as an abrasive is less plentiful. Below are listed the more important articles on the occurrence and utilization of abrasive garnet.

GENERAL

MINERAL RESOURCES OF THE UNITED STATES: Chapter on abrasives, U. S. Geol. Survey, annual, particularly volumes for 1911 and 1913.

MINERAL INDUSTRY: Chapter on abrasives, annual, particularly volumes for 1894, 1898, 1918, 1919, 1923.

ABRASIVE INDUSTRY: Cleveland, Ohio, monthly journal.

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BOWMAN, FRANCIS D., Wet sanding practice gains in favor: Abrasive Ind., vol. 5, June, 1924, p. 147.


HOOPER, F. C., The American garnet industry: Min. Ind., vol. 6, pp. 20–26, 1897.


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