HISTORY

OF THE

MINERAL RESOURCES RESEARCH CENTER

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CONTENTS

CHAPTER 1 - THE EARLY YEARS

by

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From its beginning and until very recently, the Mineral Resources Research Center (or the Mines Experiment Station as it was called for many years) has been intimately associated with the iron mining industry of Minnesota. Commercial iron mining started in Minnesota in 1884, when the first trainload of iron ore left the Soudan Mine on the Vermilion Range for Two Harbors on Lake Superior. The new industry created great interest throughout the State, and four years later a School of Mines was established at the University of Minnesota. However, it was not until 1891 that the University employed William R. Appleby, a graduate of Williams College and the Columbia School of Mines, to organize the new school and to outline a curriculum for the training of mining engineers. He was given office and laboratory space in the basement of Pillsbury Hall. Only two men were in the first class of mining engineers, which graduated in 1894, but the School rapidly increased in attendance and in popularity. Originally incorporated as a unit of the College of Engineering, Metallurgy, and the Mechanic Arts, in 1897 the School of Mines was made an independent college.[1]

Meanwhile, the mining industry of Minnesota was developing rapidly and was attracting considerable capital. In Minneapolis alone $150 million and in the State $400 million had been invested in mining companies. The interest of this growing industry had made it desirable to have an ore testing plant in Minneapolis.[2]

The 1891 Minnesota Legislature had appropriated $6,000 for new equipment for the School of Mines.[3] Professor Appleby and the Dean of the College of Engineering, Christopher Hall, realizing that the space in Pillsbury Hall assigned for this equipment was totally inadequate, conceived a scheme for erecting a separate building for the instructional equipment and at the same time securing to Minneapolis an ore testing plant. Since no University funds were available for the project, they appealed to the Minneapolis Business Men's Union to assist in raising $5,000 for a building. The Union appointed a committee consisting of E.M. Johnson, George H. Warren, P.D. McMillan, S.C. Gale, and James R. Thorpe to solicit subscriptions from business men of the city. Thorough the energy of this committee, and especially that of Messrs. Johnson, Warren, and McMillan, the amount asked was raised. Architect Harry W. Jones prepared the plans for the building without charge to the University.[4]

The ore testing plant was completed in 1895. The final cost, including machinery, was about $17,000. About $13,000 was provided by the University of Minnesota to cover the cost of introducing the water supply and sewage, for plumbing and gas fitting, and for grading about the building. The plant was of limestone, brick, and wood construction and displayed the typical lines of a western gold mill of that day, having a number of floors staggered down the steeply sloping bank of the Mississippi River at a point just south of the present building of the Mineral Resources Research Center. As part of his thesis work for graduation, one of the two members of the 1894 graduating class, Peter Christianson, had designed a small gold mill, and his ideas were incorporated in the lay-out of the machinery. Besides stamp mills, vanners, reciprocating tables, amalgamation plates, cyanidation tanks, and reciprocating boxes, bench-scale equipment suitable for the preparation of samples, such as crushers, screens, pulverizers, and the like, was installed. The primary purpose of the plant was to give mining engineering students some practical experience in ore treatment. None of the equipment in the plant was specifically intended for the treatment of iron ore, but when from time to time samples of iron ore were received, the equipment was adapted for their treatment. In time more machinery was acquired, the emphasis shifted from instruction for students to work for outsiders, and the plant became known as the Ore Testing Works. On August 28, 1902, the Ore Testing Works was partially destroyed by fire but was rebuilt.[5]

As mentioned before, the earliest commercial shipments of Minnesota iron ore came from the Vermilion Range. Shipments from the Mesabi Range did not begin until 1892. Early Mesabi mining operations were located near Virginia, Mountain Iron, and Biwabik, but the mining activities spread rapidly westward. In the land west of Hibbing sandy ores were encountered in great abundance. These ores frequently required beneficiation in some form, that is, the ores needed some type of treatment that would improve their grade and structure. Engineers of the Oliver Iron Mining Company did much bench-scale testing and later shipped samples away for small pilot-plant testing. In 1906 Oliver built a testing mill at Trout Lake near Coleraine, Minnesota. As a result of an extensive investigative program carried out in the testing mill, a large concentrator was designed and constructed at Trout Lake to treat iron ores from various Oliver mines in the western Mesabi Range. The concentrator went into operation in 1910 and was such a success that other iron-mine operators became greatly interested in the possible improvement of their ores by similar means.

Professor Appleby realized that the School of Mines could be of great help to the iron mining industry if a trained staff and equipment suitable for the testing of the Mesabi sandy ores were available. As a result of his endeavors the Board of Regents of the University in 1911 authorized the establishment of a School of Mines Experiment Station and the State Legislature appropriated a modest sum of money ($10,000) to finance its operation. The stated purpose of the Station was as follows: to promote the development of the mining and mineral resources of the State; to assay specimens of ores, clays, and minerals; to make such assays free of charge for private parties, subject to such regulations as the Board of Regents might deem necessary; to make mining and metallurgical experiments in the treatment of such substances and in the utilization of mining and metallurgical by-products; to investigate methods of mining and the use of explosives; to undertake such other mining and metallurgical problems as might seen to be desirable; to make all ore estimates for the Tax Commission;[6] and to do such other work along the lines mentioned as might be requested by other State departments. Edmund Newton, a graduate mining engineer from the Columbia School of Mines, was employed as Superintendent of the newly formed Station and William Appleby, who was now Dean of the School of Mines, was designated Director.

Meanwhile, in 1903 the School of Mines had moved from its crowded quarters in the basement of Pillsbury Hall into a new, specially designed building just across the street (East River Road) from the Ore Testing Works. This is the building presently occupied by the Institute of Child Development. Newton, on coming to Minnesota, was given office and laboratory space in the new School of Mines building and plans were made to modify the Ore Testing Works so that it could be used as a laboratory for the study of iron ore beneficiation.

In 1912 Neil S. Kingsley was employed as an engineer to assist Superintendent Newton with the modification in the Ore Testing Works, now called the Mines Experiment Station, for more effective use. New shop space was provided for a millwright and a machinist and rather crude but very serviceable equipment was installed for the screening and washing of iron ores. At that time, the screening out of coarse rock and its rejection, and the removal of fine sand by washing were the principal accomplishments of iron ore beneficiation plants. As time passed there was a growing awareness of a need for more effective concentrating procedures. The Station staff then began to give much thought to tabling and especially to jigging. A set of Woodbury jigs was an early acquisition of the Station. Along with tabling and jigging, grinding in open and closed circuits to improve the concentrate grade and recovery was studied.

During the first year of the Station's existence, the staff made a few preliminary studies on the treatment of low-grade iron ores. Most of the tests were made on ore samples from the Mesabi Range, but a few tests were also made on samples from the Cuyuna Range, which had recently opened up. It was immiediately apparent that the State, which owned (and still owns) large tonnages of such ores would be particularly benefited by such tests. The Tax Commission, too, would be materially assisted in placing a fair valuation on ore lands owned by private companies. Though no large-scale concentration tests were made for mining companies in 1911-12, in view of the interest being shown by certain companies in the Station's work, and because of the exploration of new low-grade ore land, it seemed probable that the Station would be called upon to make such tests in the future.

The object of new Experiment Station quickly became well known and the number of applicants for assistance and technical advice increased steadily. After many requests for detailed information concerning mining operations in the State had suggested the advisability of issuing a publication on the subject, Professor Charles E. van Barneveld prepared a bulletin entitled Iron Mining in Minnesota. It was the first publication of the newly established Station and the subject matter in the bulletin proved to be of great interest both to technical men and to the general public.[7]

In the excitement of the 1890's on the Mesabi Range, while new bodies of high-grade ore were constantly being sought and discovered, public interest had been naturally centered upon the exploration of new territory in the hope of finding rich deposits. The individual need of quick returns on heavy investments had led to the selective mining of the best-grade ore, resulting in an enormous waste of natural resources.

By 1912 the Mesabi Range had been carefully probed. The outlines of the iron-bearing formation were quite accurately known, and the location of both low-grade and high-grade ore bodies had been determined by thousands of drill holes. Very few new deposits of high-grade ore were being discovered. In mining, the idea of greatest ultimate profit had replaced that of quick return on investments. Cheap transportation, the rapid mining of the higher-grade ore, and the lowering of the "base grade" on which the ores were sold had resulted in an increased interest in the utilization of the vast tonnages of low-grade ore already proven.

Because of the wide-spread interest in the problem and the vague ideas very generally existing as to why some low-grade ores could be concentrated up to grade and others could not, the Station late in 1912 took up a detailed study of low-grade Mesabi ores. Through the courtesy of many of the mining companies, approximately 1,800 sacks of ore, holding 100 pounds each, were secured for this purpose. Accumulating this ore involved several trips to the Range by members of the Station staff in order to superintend the selecting and shipping of this ore for experimental purposes. Every material assistance was rendered by the mining companies in this regard.

The apparatus available at the Station for the testing of these ores was very limited. Before any work could be done it was essential to design and construct suitable machinery for this prupose. This necessarily consumed much time and, after the machinery had been built, numerous modifications were required for the successful operation of the several units. In the end, however, a small washing plant was assembled at the Station, which conformed with the commercial practice found on the Mesabi Range at that time. A standard procedure was adopted and the samples which had been collected were tested during 1912-13. The purpose of this preliminary study was not to develop new machines or new methods of treatment, but rather to study the physical and chemical characterstics of the ores and their amenability to the washing process. Incidentally, it was necessary to make over a hundred screen analyses to determine the distribution of material on different size screens, and over a thousand determinations for iron and silica. Determinations for phosphorus, alumininum, and "loss on ignition" would have made the data more valuable but were impossible on account of a lack of funds.

The foregoing work was described in detailed in Bulletin No. 2, Preliminary Concentration Tests on Mesabi Ores, which was prinited and distributed late in 1913. The Bulletin was very favorably received throughout the iron mining community.[6] The study showed that before definite conclusions could be reached concerning a particular ore, a large number of tests would have to be made. Furthermore, it was evident that the physical and chemical characteristics of an ore noticeably affected the results obtained by washing. In fact, it was found that material from different layers or classes of material in the same ore body behaved very differently on washing.

In July 1913, members of the Experiment Station staff went again to the Mesabi Range and shipped back to the Stations fifty-five samples of one ton each. The geological relations of these samples were carefully noted. However, work on these materials was delayed for a year owing to requests from numerous companies on the Mesabi Range to test their particular ores.

The development of the Cuyuna Range presented very different and much more complex problems in iron ore concentration. Between 1904 and 1911 drill holes on the Cuyuna had shown up large tonnage of material running from 40 to 45 percent iron; that is, they were somewhat low in grade. In fact, there appeared to be more of this material than high-grade (merchantable) material. Ores of such iron content on the Mesabi Range could be brought to merchantable grade by the relatively simple and cheap washing process. At first it was believed that the same would be true of the Cuyuna ores, but the subsequent development of the Cuyuna ore bodies showed that the structures and other physical characteristics of these ores were quite different from those of the low-grade Mesabi ores. In most of the Cuyuna ores the leaching of the silica by natural waters was very incomplete. A portion of this silica was "sand", but the remainder consisted of large chunks that could not be eliminated by standard washing. Crushing followed by jigging or possibly magnetic concentrations after reduction roasting appeared to be the most likely solutions.

Late in 1913 samples of soft, hydrated hematite ore from the Thompson Mine on the Cuyuna Range were submitted by William Wearne of the Inland Steel Company. They were concentrated by log washing. Other samples of Cuyuna sandy and cherty ore from the Kennedy Mine, submitted by George N. Crosby of the Crosby Exploration Company were concentrated by log washing and jigging.

Edward W. Davis came to the School of Mines in the fall of 1912 to serve as an instructor in mathematics. He was a graduate of Purdue University with a degree in electrical engineering. Shortly after his arrival at the School, the Regent from Duluth, John G. Williams, brought in a sample of iron-bearing rock from a track of land west of the town of Mesabi that a group of his associates controlled. The rock, which is called taconite in Minnesota, contained particles of the magnetic iron oxide, magnetite. Because Davis knew something about electromagnetism, he was asked to be present during a discussion of possible utilization of the rock. His preliminary tests, with a mortar and pestle and a hand magnet as his principal items of testing equipment, resulted in the recovery of a concentrate that he then thought to be quite acceptable. It was suggested that he try to devise more effective means of testing and to think about the sorts of equipment that might be suited for the commercial treatment of the rock. Davis soon became very much interested in finding solutions to these problems and became involved in work that occupied much of his future life and brought him fame for his many contributions. Davis was assigned the part-time title of Engineer on the Mines Experiment Station staff and desk space was provided for him in the new office of the Station.

In February 1913 a fire seriously damaged the interior of the School of Mines Building, and the School was forced to occupy temporary space wherever it could be found, principally in the basement of the Engineering Building (now Lind Hall) and in the Engineering Experiment Station (now the Experimental Engineering Building). The fire did not damage the Mines Experiment Station, but certain changes in it became necessary because of the vacating of the School of Mines Building. About half of the floor space in the Station was taken over for use by the students in fire assaying. In one corner of this space a laboratory hood was installed and the most meager facilities were provided for the making of wet chemical analyses. A long, narrow office was built along the south side of the building to provide desk space for Newton, Kingsley, and an engineering student who came in for a few hours a week to do any typing that might be required.[8]

Mr. Kingsley resigned as engineering assistant in May 1914 and was succeeded by Mr. Ernest Larson. After serving for about a year, Mr. Larson left to become superintendent of a new washing plant at the Thompson Mine on the Cuyuna Range. This plant was just one of many that were built following successful tests made at the Experiment Station on Cuyuna Range ores.

Besides the people who have been mentioned, the staff during these years also included a millwright, a machinist, two chemists, and an ore sampler, Adolph Johnson. Mr. Johnson had been born and raised in a home on the river flats near the site of the present heating plant. Although his formal education was quite limited, Mr. Johnson was an unusually capable person who served the Station well until his early death in the mid-twenties. During the summer of 1915 both of the chemists resigned, rendering the Station incapable of analytical work for several months.

The work on taconite progressed rapidly after the problem had been brought to the attention of Mr. Davis. In July 1914 he made a trip to the eastern Mesabi Range and secured about a thousand pounds of representative material for experimental purposes. Only a dry magnetic separator was available at the Station for testing. Davis soon found that with the fine grinding necessary to liberate the grains of magnetic in the taconite, wet magnetic separation was absolutely necessary. He first built a powerful electromagnet and by manipulating a glass tube filled with a mixture of ore and water near the electromagnet, he was able to make very satisfactory tests on small samples. Later mechanized, the magnetic tube concentrator became indispensable whenever work was being done at the Station on finely ground magnetic ores. In fact, its use has since spread throughout the world, and it would be difficult to find a mineral dressing laboratory anywhere that is not equipped with a Davis magnetic tube concentrator. From the results secured by the use of the concentrator, it is possible to determine not only the amount of magnetic material in an ore sample but also the grade of concentrate that can be made when the ore is crushed to various sizes. The electromagnet that was built to Davis' design for the original concentrator is still in use at the Mineral Resources Research Center.

However, since the amount of ore that could be concentrated in the magnetic tube was very small, a special magnetic log washer was evolved by the Experiment Station staff. As the name inplies, this machine was similar to the log washer then in common use in Minnesota. Electromagnets were applied to the lower side of the machines in such a manner as to place the whole bottom of the trough in a magnetic field. The first model of the washer was small in size, only two feet in length, but within a year a five-foot model was operating at the Station. During 1914-15 much work was done at the Station with this model to determine the capacity and proper working conditions of a commercial machine.[9]

Pleased with the results of the bench-scale tests conducted by Mr. Davis, in 1915 Regent Williams interested associates of a Mr. D.C. Jackling in the possibilities of treating magnetic taconite in a commercial plant. Mr. Jackling had gained fame because of his successful endeavors to treat low-grade copper ores. His interest in the treatment of low-grade iron-bearing rock seemed to be quite natural. An organization called the Mesabi Syndicate was formed to finance further taconite studies. Soon thereafter the Syndicate authorized the purchase of some grinding and concentrating equipment for a series of taconite tests at the Station.

About this time I became a member of the Station staff. During my years in high school in Hopkins (1907-1911), I had naturally given some thought to a future course of study at the University or elsewhere. My older brother had warned me that all of the departments in the College of Engineering and also the School of Mines required freshmen to take an English course that he had disliked because of the many themes demanded. In 1911 the School of Mines instituted a five-year curriculum which included a sub-freshman (largely preparatory) year. However, an entering student, by passing special examinations in high school English and mathematics, could omit the entire sub-freshman year, and by so doing would not be required to take freshman English. This was for me and I immediately acquired an interest in mining and metallurgy. I have never regretted my decision to make those subjects my lifework.

I received my degree in mining engineering from the Minnesota School of Mines in June 1915. A new School of Mines Building (the present Appleby Hall) had just been completed to replace the one gutted by fire. I accepted temporary employment at the School helping the staff to get the Building settled and the equipment arranged for classes in the fall. Dean Appleby told me that there would be an opening for an Engineer at the Mines Experiment Station later in the summer and offered me the position on the condition that I would promise to stay for at least a full year. With some hesitation I accepted this condition and on September first I became a member of the Experiment Station staff.

The summer vacation was still in progress and the Station seemed quite deserted when I reported for work. Mr. Newton, the superintendent, informed me that he was leaving the city for a short time and that I would be in charge during the interval. He said that the crew had work already assigned and would need little if any supervision. He then gave a map that showed all the counties in the United States. He also gave me a tabulation of county populations. He said that he wanted to know the geographic center of population of the United States and that the making of this calculation would provide a way for me to learn the use of a mechanical calculator. The problem kept me busy for quite a while and did indeed provide an effective means for providing experience in the use of a calculator. About the time that the calculation was completed I received word that Mr. Newton's trip would extend for another month. The following weeks, during which I had very little to do, were the longest that I ever experienced at the Station. Never again would there be a time when there would not be many more problems needing serious attention than could possibly be completely studied.

One project helped considerably to occupy the rest of the summer. Toward the end of Mr. Newton's absence, some crates of machinery parts arrived at the Station from the Dorr Company, the first of several items of machinery that had been ordered by the Mesabi Syndicate for use in the taconite studies. At that time the Dorr Company frequently mentioned in their advertising that they could pack their equipment so that there would be no piece too large to be easily carried on the back of a burro. The first shipment proved to be parts for a Dorr duplex classifier, apparently crated to meet the conditions of their advertising. It consisted of numerous plates cut to size and drilled for riveting, together with many bags and packages of rivets, bolts, miscellaneous castings, and other parts. The fitting together of this machine was about as confusing as the assembling of a modern radio from a kit except that the Dorr Company had provided no detailed instructions. We had ample time, however, and the classifier was finally in one piece.

Meanwhile, Mr. W.G. Swart, who was in charge of experimental work for the Mesabi Syndicate, had obtained other items of equipment for the taconite studies. Besides the Dorr classifier mentioned above, he installed a four-foot Harding mill and a small Richard-Janney classifier. These pieces of equipment arrived on schedule and by late October 1915 we were able to set up a small taconite pilot plant in which the newly invented magnetic log washer was the principal concentrating device.

During the final stages of the assembling of the taconite pilot plant, Mr. Newton and Mr. Davis returned from their summer vacations, and people employed by the Mesabi Syndicate also began to arrive. Besides Mr. Swart, these included Mr. Fred Jordan, who later became general superintendent of the Mesabi Iron Company, the successor to the Mesabi Syndicate and Mr. T.B. Counselman, who was to become metallurgist at the Babbitt Plant of Mesabi Iron.

A new chemist, Mr. James A. McCarty, was hired by the Station to replace the two who had left. Since Mr. McCarty had been with the Oliver Mining Company at Virginia, Minnesota, for a number of years, he was a very able ore assayer. He soon made plans for a new chemical laboratory and the University authorized the construction of this much needed facility.

As soon as the equipment of the taconite flowsheet was operable, an active testing program was crowded forward as quickly as possible by Mr. Newton and Mr. Davis. A series of grinding and concentrating tests during the spring of 1916 gave metallurgical results that were quite encouraging.

While the tests of the taconite flowsheet were underway at the Mines Experiment Station, the Mesabi Syndicate was making arrangements for a larger and more conveniently situated taconite pilot plant at Duluth. These arrangements were completed rapidly and during the summer of 1916 the taconite testing facilities at the Experiment Station were dismantled and shipped to Duluth where they were reassembled and used until the end of 1918. In addition to an involved testing program, the operators of the Duluth pilot plant were also assigned the task of producing a cargo of high-iron, low-phosphorus, sintered concentrate to satisfy a Government request. Production of this sinter was finally accomplished and the shipment was made.

With the shifting of most of the taconite studies to Duluth, the principal work of the Experiment Station returned to the testing of iron ores by gravity methods, endeavors to find ways of utilizing the lower-grade hematite ores of the Mesabi and Cuyuna Ranges, and especially to studies of the manganiferous iron ores of the Cuyuna. The latter investigations resulted in the publication of a Station bulletin relating to the use of Cuyuna ores and the building of several small commercial plants on the Cuyuna Range.[10]

During 1916 negotiations were underway between the University of Minnesota and the United States Bureau of Mines relating to the establishment of a Bureau of Mines Station on the University campus. The Bureau's general program called for the establishment of ten stations at strategic locations in various parts of the United States. Arrangements were finally completed for the establishment of one of them in Minneapolis, to be known as the Lake Superior Station. The announcement of this decision was made early in 1917 and the Bureau's Station was dedicated in June.

There were no suitable office or laboratory facilities available for use by the Bureau at that time. When the first three Bureau staff members arrived, consisting of Mr. P.H. Royster, metallurgist; Mr. J.A.T. Addison, messenger; and Mr. B.F. Myers, secretary; they were given office space in the School of Mines (now Appleby Hall). However, the University Department of Building and Grounds quite promptly designed and built a small office building for the exclusive use of the Bureau. This building adjoined the Mines Experiment Station and was just south of it. It was a rather nice looking little structure and provided very pleasant quarters for the Bureau staff for the next six years.

Some after its establishment, the Bureau's Lake Superior Station and the State's Mines Experiment because very much involved in activities relating to World War I. One of the most important of these activities was a study of domestic deposits of manganese ore. German submaries had made the importation of manganese ore, so necessary in the manufacture of steel, both dangerous and expensive. Hence the Government had become interested in locating sources of manganese ore that would not require long ocean voyages to reach our steel centers. A program was set up in which samples of manganese ore were collected by Government geologists from promising domestic sources and then were tested by gravity methods at the Mines Experiment Station. However, the War ended before the results of the work could be given any practical application.

In late 1919 the Bureau staff in cooperation with the School of Mines built a small, experimental blast furnaces in the yard behind the School of Mines building (now Appleby Hall), since space was not available in the Mines Experiment Station or adjacent to it. Attached to this minature blast furnace were all necessary means for making observations and securing scientific data covering all conditions affecting the results obtained in its operations. Special openings up the side of the furnace were provided so as to make it possible to obtain samples of gas and solid materials from various elevations of the furnace as a means of studying the more important chemical and physical reactions occuring in the process. Temperature and pressure observations taken at the same elevations furnished further information of value in making a logical interpretations of these reactors.

The first object of the initial research with this furnace was to establish means for smelting iron and manganese ores in such a way that it could be determined in advance of operation in a commercial furnace how certain ores would react and how they could best be treated. The second object was to determine from the operation of this small furnace the proper design for a larger experimental furnace which was being contemplated. Initial studies with this furnace by P.H. Royster, G.E. Ingersoll, and others were devoted to the investigation of low-grade manganese ores.[10] Other investigations continued with this furnace and others of various shapes and dimensions at intervals during the next three years.

Shortly after the close of World War I, the Duluth taconite pilot plant closed and much of the grinding, concentrating, and testing equipment in the plant was given to the Mines Experiment Station by the Mesabi Syndicate. Mr. Davis, who had been with the Mesabi Syndicate on a two-year leave of absence from the University, returned to the Station as Superintendent, filling the vacancy caused by the resignation of Mr. Newton some time previously. During the War Mr. Newton had been called to Washington as a metallurgical consultant for the Government. There he had remained until the termination of the War and then had not returned to the Experiment Station. Mr. Davis' experience with the Mesabi Syndicate had broadened his interest in Minnesota iron mining. He returned to the Experiment Station not only filled with enthusiasm for the possibilities of utilizing taconite, but also intensively interested in the problems of the operators of the natural ore mines. He almost immediately began improving the facilities of the Station and expanding its activities. He was successful in interesting the Legislature in the potential value of the Station to the State and obtained increase appropriations for operating expenses.

Several other people joined the staff about this time. One of these was Mr. John J. Craig, a graduate of the Minnesota School of Mines in 1916. He had served as an officer in the United States Army and had returned to the University as an instructor in mathematics in the College of Engineering prior to coming to the Station. Mr. Craig was destined to become an outstanding research metallurgist for the Station for the next twenty-one years.

With the closing of the Duluth plant, the Mesabi Syndicate was disbanded and the Mesabi Iron Company was formed for the purpose of financing, designing, erecting, and operating a commercial magnetic taconite plant at Babbitt, Minnesota. Mr. Davis continued to do a little consulting work for them, and it was quite natural that a variety of problems relating to the treatment of magnetic taconite at the Babbitt Plant received attention at the Experiment Station. The Babbitt Plant closed in 1924 and no further taconite studies were made at the Station until the late 1930's.

During the period between 1911 and the end of World War I a number of washing plants (perhaps fifteen or twenty) had been built and put into operation in Minnesota, principally on the western Mesabi Range. Most of these plants used a flowsheet that resembled the one used at the Trout Lakes plant at Coleraine. As originally built the Trout Lake plant had several units all housed in one large building. The later plants were similar but smaller, generally classified as half-unit, one-unit, or two-unit plants. At the conclusion of the War, the operators of these plants were interested in modifying these plants either for more effective concentration or for lower operating cost. These desires resulted in increased use of the testing facilities available to those at the Mines Experiment Station. Most of the mechanical equipment and supervision of the actual tests was put under my attention. Mr. Craig gave more heed to the activities in the office, including the compilation, calculation and tabulation of the test data and the preparation of reports.

One of the results of this experience gained by the Station staff through working on the low-grade iron ores of the western Mesabi was a new type of concentrating machine, which was developed in 1918-19. The machine was essentially a standard rake classifier with a trommel screen placed crossways over its lower end. Fresh ore was fed into the trommel, which rejected the coarsest particles and dropped the finer particles into the classifier pool. The classifier rakes then made two additional products, a fine overflow and a coarser underflow. After a working model had been built and tested by the Station, the machine was manufactured and marketed by the Dorr Company of Denver, Colorado. A royalty of four percent of the purchase price of each machine installed was to be paid to the University. The first two installations of the concentrator, called the Dorr Washer, were completed during the summer of 1920, one at a plant of the Tennessee Iron and Coal Company, washing iron nodules out of clay, and the other on the Mesabi Range at the Mariska Mine of the Bowe-Burke Mining Company.[12] The results produced at these applications were even more satisfactory than those secured with the small experimental machine that had been built at the Station. During the following years Minnesota iron ore operators were able to treat a considerable tonnage of low-grade washer ore with the Dorr Washer that could not be handled by any other machine.[13]

In keeping with the original purposes of the Station, during these early years fully half the effort of the staff was devoted to examining, assaying, and testing, free of charge, specimens of ores, clays, and minerals which were submitted by individuals and companies located in the State. The speciminums varied in size from a few ounces to several tons.

Hundreds of mineral specimens were assayed in 1911-12, the first year of the Station's existence, and over two hundred consultations were held with individuals relating to their properties and economic possibilities. During the following year the staff conducted numerous brick and clay tests and analyzed hundreds of other mineral samples. Specifically, the work included visual examinations and assays for private parties, burning clay for the Minnesota Geological Survey, and analyses of special samples for the State Mine Inspector, Mr. F.A. Wilder. It was frequently of utmost importance that the analyses for Mr. Wilder be obtained without delay. As a consequence, the members of the Station staff often worked fourteen to fifteen hours a day in order that the results might be reported promptly.

During 1913-14 nearly three hundred mineral samples were brought to the attention of the Mines Experiment Station. The work done on these samples included the burning of clay for the Minnesota Geological Survey, assays for gold and silver, and examinations of small hand specimuns. All samples submitted were from the State of Minnesota.

Only 147 different mineral samples were received in 1914-15. The work included again the burning of clay and assays of specimens for gold and silver. Eighty-nine samples were submitted which required only sight examination or simple blow-pipe tests to identify. Much time was spent in consultation with citizens of the State who presented their samples in person.

During 1915-16, 196 small tests were made. The work included assaying some samples for gold and silver. One hundred nineteen samples required only sight examinations or blow-pipe tests. Many citizens took advantage of the privilege of appearing in person, submitting their samples, and receiving professional advice. The Minnesota Geological Survey was then working on the geology of titaniferous iron ore deposits that had been discovered in Cook and Lake Counties. Small samples taken from these deposits were submitted to the Station by the Survey for the purposes of determining whether their grades could be improved by metallurgical treatment.

Informal cooperation between the United States Geological Survey and the Experiment Station was effected during 1916-17, by which the Experiment Station would in connection with its metallurgical investigations, make such chemical and physical analyses, concentration tests, and other metallurgical studies of iron ores, and of other ores and rocks submitted by the United States Geological Survey as might have had a direct practical bearing upon the study of the economic geology of these ores by the Federal Survey.

Between 1916 and 1919 an average of 350 small (under one ton) tests and about six large (over one ton) tests were performed each year. In addition, various experiments were carried out in order to determine possible improvements in the methods of testing being used. Cooperation tests with the Minnesota Geological Survey included numerous concentrations tests on titaniferous iron ores and assays of reported gold-bearing material from various locations in the State.[14]

Perhaps the best known publications of the Mineral Resources Research Center, especially by the owners and operators of Minnesota iron mines, has been the Mining Directory. However, ideas for several other periodicals preceded its initial publication.

During its first years of existence, the Station had begun preparing under the direction of Professor Elton H. Comstock a file of maps of the Minnesota iron ranges. In later years the Station staff initiated the practice of updating the maps annually and of making copies of the maps available to interested parties at a nominial charge. The maps were very well received and generated many requests for more.

One day in May 1915 during a visit to Duluth, Edmund Newton was having an informal discussion with J. Uno Sebenius of the Oliver Iron Mining Company. After they had talked about several subjects, Newton mentioned the general plan that he had for a proposed bulletin on Beneficiation Practice to be published by the Station. Sebenius countered with the suggestion that the Station start a series of publications which might be termed a "Mining" or an "Economic" series and which would treat thoroughly and in an authoritative way all phases of the iron mining industry in Minnesota. Sebenius and his assistant, W.P. Wolff, thought that the two topics most worthy of presentation were Benefication Practice and Mining Economics.

Upon his return to the Station, Newton reported the remarks of Sebenius and Wolff to Dean Appleby and advocated dividing the Station into two sections: an experimental branch for carrying out research work along technical lines and an economic branch for assembling and organizing actual practical data, and statistics. Two series of publications reflecting these divisions would naturally follow. If the work were initiated at once, it would necessarily proceed slowly because of the Station's limited means. However, such a comprehensive scheme already in operation would probably aid in the establishment of a U.S. Bureau of Mines station in Minneapolis, which was being contemplated at the time. Though Newton's hopes for these publications were never realized, a third concept was later contributed to the plan for an information periodical.

During his years in Duluth, Mr. Davis had accumulated a card file of Minnesota iron ore properties which he had found very useful. Upon his return to the Station, he expressed his thought that there was a need for a publication that would list the various mines and give concise information as to their location, ownership, shipments, reserves, and other pertinent data. Subsequently the staff combined their efforts and, using the card file of Mr. Davis as a start, prepared such a booklet. It was called the Mining Directory of Minnesota and the first issue was published in 1920. The Directory included the Comstock maps of the Minnesota iron ranges, legal descriptions of nearly 500 mining properties, a list of operating and fee holding companies, and a register of some of the mining people with their addresses and company affiliations. If the Directory appeared to be of sufficient value to the mining public, it was planned to update and reissue it each year. The response to the first issue was overwhelming. Evidently the book filled an urgent requirement, and the mining companies of Minnesota were very interested in its continued publication. They indicated that they would be most cooperative in supplying the needed information. The Directory continued to appear annually from then on. Mr. Craig was assigned the duty of compling subsequent issues. He continued to edit the Directory until he left the University twenty years later.

This chapter has been a review of the early years of the Experiment Station as they have been documented and as I remember a few of the details. With the return of E.W. Davis to the Station in 1918, with the occupancy of a new building having greatly improved facilities in 1923, and with increased cooperation by the State Legislature in providing necessary funds, the work of the Station increased significantly as will be described in subsequent chapters.

In the early days of iron mining in Minnesota, when people spoke of the enormous reserves of the Mesabi Range, they were thinking in terms of the high-grade oxidized (direct shipping) ores. Subsequent shipments of nearly two billion tons has nearly depleted this wonderful asset. Washing, jigging, and heavy-density separation added nearly three quarters of a billion tons to that total in the form of gravity concentrates. I like to believe that work at the Station in gravity concentration helped a little to produce this significant tonnage and may have made it a little easier for the operators to produce the very large annual tonnages that were demanded of them during the years of World War II.

The reserves of direct shipping ores and of gravity concentrates are now practically exhausted, but nevertheless mining continues to be a very important industry in northern Minnesota. It is fortunate that a few men such as E.W. Davis firmly believed that the hugh reserves of magnetic taconite on the Mesabi Range could eventually be utilized. The work that he promoted toward this development was certainly helpful and very timely. Minnesota now has the potential to provide our steel industry with adequate supplies of iron ore for countless generations to come.

When I left the University in 1962, it was with a very satisfied feeling that the organization with which I had so long been associated had indeed made valuable contributions in the past and would undoubtedly continue to do so in the future.

CHAPTER 2. - THE TWENTIES AND THIRTIES

Early in 1923 the staff of the Mines Experiment Station moved into a new, large, modern, and superbly designed building. There in the next two decades they were able to pursue important investigations in gravity concentration and the direct reduction of iron ores, besides being of tremendous aid to many companies and individuals in solving their problems.

Since its establishment in 1911, the Mines Experiment Station had been occupying the Ore Testing Works, a building originally constructed in 1895 for the instruction of students. However, the volume of work pressed upon the Station soon forced the students from the building. In 1917 the United States Bureau of Mines also began doing work in the building. In spite of the overcrowded conditions in the Ore Testing works and the deteriorating condition of the structure, no new construction had been possible due to the War.

In 1916 the University had promised the Bureau of Mines a suitable building if the Bureau would locate one of its experiment stations on the University campus. The Lake Superior Station of the Bureau of Mines was subsequently established at the University in June 1917. However, due to a lack of funds the University was able to construct for the Bureau only a small frame addition to the Ore Testing Works. This building which cost about $6,000 provided temporary office quarters for the Bureau but no laboratories. The Bureau was able to conduct only such experimental work as could be carried on in the already overcrowded Ore Testing Works. In order to work out definite problems assigned to the Lake Superior Station for immediate investigation, the Bureau was compelled to erect, at no expense to the University, a fuel-testing laboratory, together with an experimental blast furnace, the latter unhoused for lack of funds. It was impossible to undertake the main investigations for which the Lake Superior Station was originally established. To provide necessary laboratory facilities for the chemists on the Bureau of Mines' staff, two rooms in use for educational work in the School of Mines Building (now Appleby Hall) had to be given up and turned over to the Bureau. This arrangement was extremely unsatisfactory to both parties. While these rooms were urgently needed for educational work, they were proving inadequate for even the limited amount of chemical work being carried on by the Bureau.[1]

In a 1917 contract with the Bureau of Mines in fulfillment of the above promise, the University Board of Regents had agreed to ask the Legislature for a building to cost no less than $150,000. On account of the War, however, the Bureau of Mines permitted the Regents to postpone their request to the Legislature for a new building, without considering the former contract broken. When preparing its legislative budget for building in 1918, assurance was given to Mr. Julihn, the head of the Lake Superior Bureau of Mines Station, that an appropriation would be secured during the next biennial period and that a building would be erected out of the first year of funds available. Subsequently, the Regents obtained from the Legislature $150,000 for the erection of the Experiment Station and another $25,000 for equipment.

In November 1919 the Building and the Grounds Committee of the Board of Regents took up for consideration the development of the University's post-war comprehensive building plan. Part of the plan was the construction of a new building for the Mines Experiment Station and the Lake Superior Station of the United States Bureau of Mines. However, the committee felt that the high cost of construction in 1919 would not permit the erection of a suitable building for the $150,000 that had been secured, and wanted to postpone the erection of the building for about a year.

During the next four months, the University President, Marion L. Burton, consulted with William Appleby, the Dean of the School of Mines; C.E. Julihn, the Head of the Lake Superior Station; and Mr. Van Hise Manning, the Director of the United States Bureau of Mines regarding the proposed building. Fred B. Snyder, the Regent representative for the School of Mines, was also involved. Appleby and Julihn were, of course, in favor of immediate construction, both because the need was pressing and because the University's promise to the Bureau was then three years old. In January 1920, Appleby pointed out to Burton that if the University were going to commence the building in the following July, when the appropriation would become available, the University should begin to detail plans immediately.[2]

Snyder was of the opinion that construction should be started with the funds available and that the additional money to make a suitable building should be obtained from the first money available in 1921.[3]

A School of Mines building committee, consisting of C.E. Julihn of the U.S. Bureau of Mines; E.W. Davis, Superintendent of the Mines Experiment Station; and Professors Christianson, Pease, and Comstock, considered cutting down the size of the building but decided that they could not sacrifice a single square foot of space.[4]

On the other hand, Van Hise Manning, the Director of the Bureau of Mines, was immediately inclined to agree with President Burton that it would be advisable to postpone the construction of the building for a year or so in the hope that building costs would moderate.[5] Finally after a conference in Washington between Manning and Burton, it was agreed that the beginning of construction of the new building would be postponed until July 1, 1921.[6] The cost of the building would be whatever sum might be required to erect such a building as could have been provided for $150,000 in October, 1918, when the agreement between the University and the Bureau was made.[7] Later this date was amended to December, 1916, when the Board of Regents had just decided to include in its building program $150,000 for a Mines Experiment Station.[8]

When James H. Forsythe of the University Department of Architecture was authorized in July 1919 to make preliminary studies for the new Mines Experiment Station, he was given to understand that the building would be built on Pleasant Street between the School of Mines (now Appleby Hall) and Washington Avenue. While this location was very steep and awkward, it was the only one available near the School of Mines. However, eighteen months later the site for the new building had not yet been definitely determined.[9]

Part of the problem of the location of the building was the Northern Pacific tracks which then cut across the campus from a point just south of Millard (now Wulling) Hall to the intersection of University Avenue and Oak Street. The presence of the tracks seriously limited the space available on the north side of the School of Mines building, even if the proposed geology wing to the School of Mines were not built. (To this day the wing has not been built, and the north wall of Appleby Hall presents an unfinished appearance to a campus visitor.)

Dean Appleby had not considered any site other than the one on Pleasant Avenue. He felt that President Burton had assured him that the new building would be erected there. In fact Appleby had planned the general disposition of the machinery and the special features of the building with hillside location of this site in view.[10]

In answer to a December 1920 inquiry from Appleby, Coffman said that it would not be possible to locate the building until the whole question of the covering or the removal of the Northern Pacific tracks had been resolved.[11]

One month later Appleby again called Coffman's attention to the necessity of locating the Mines Experiment Station at the earliest possible date. In his opinion, the site located between the School of Mines Building and Washington Avenue Southeast would serve both the Bureau of Mines and the Mines Experiment Station most advantageously.[12]

Again Coffman replied that it was not possible to locate the new building until the question of the covering or the removal of the Northern Pacific tracks had been determined upon. He added that the Regents did not look with favor at the site between the School of Mines Building and Washington Avenue Southeast.[13]

In February 1921 the University Comptroller, Albert J. Lobb, reminded President Coffman that unless action was taken in the very near future and plan begun, it would be impossible for the University to live up to its agreement with the Bureau of Mines that actual construction would begin by July 1, 1921.[14]

Late in March Dean Appleby again sought assurance from President Coffman that the Legislature would take some action concerning the Northern Pacific tracks, that the Board of Regents at its next meeting would decide on the site for the new building, and would authorize the immediate preparation of plans for the building. In the past, Appleby said, he had favored a hill site, but a recent trip west and conferences that he had had with some of the best technical men in the country had converted him without reservations to a level site. Appleby pointed out that when the Ore Testing Works had been built in 1895 on the river bank north of the Northern Pacific tracks, no Bureau of Mines station or Mines Experiment Station existed and the building had been built mainly for educational purposes. The great distance between the Ore Testing Works and the second School of Mines Building, which had been built in 1913, had seriously handicapped him in administering successfully and efficiently the work being carried on. A new Experiment Station Dean Appleby felt, should therefore be located in close proximity to the School of Mines Building. The Bureau's station, too, should occupy a site easily accessible to the general public. It had been exceedingly difficult for visitors, particularly those from out of town, to find the Bureau of Mines station where it then was, in back of all University buildings and far removed from the main walks covering the campus. At one time, Appleby said, some members of the Mines faculty had been in favor of locating where trackage facilities were available. However, since in those days parties shipping ore to the Experiment Station for testing were paying all transportation charges and since most of the ore samples coming in were less than carload lots, it appeared to Dean Appleby that no great advantage would be gained in having a siding into or alongside the building.[15]

Coffman replied that the Board of Regents were of the opinion to wait until the Legislature had finally acted on the Legislature had finally acted on the removal of the tracks.[16]

When Appleby saw the construction of the building disappearing into the dim future, he withdrew all his objections to a site distant from the School of Mines. Professor Forsythe then promptly recommended a location in the northwest corner of the campus near the Ore Testing Works. The Board of Regents quickly approved the recommendation (May 9, 1921) and made a public announcement.

The announcement took the Department of Education by surprise and they objected to the location, citing that it would decrease the amount of space available for womens athletics in the northwest corner of the campus. Their objections were considered by the Board of Regents but a study showed that the new building would not encroach on the athletic field but would be near the river bank.

Ground was broken for the new building in June 1922 and the corner stone was laid May 16, 1923. The Northern Pacific tracks were not removed from the campus until 1924. However, a connection was made from tracks on the west side of the river to the Great Northern tracks north of the campus over a new bridge. A spur to the new Station was added later.

On April 24, 1923, the Station staff started moving into the new Experiment Station building. The moving operation was completed during the summer of 1923 and by mid-1924 most the of the equipment had been installed. However, the large amount of construction work that continued through these years made it impossible to get the laboratory into a smoothly operating condition. Hence, the staff was not able to devote their complete attention to metallurgical and experimental work until late in 1925.

Early in 1923 as the new building neared completion, Superintendent Davis sought the help of Dean Appleby and President Coffman in obtaining about $5,200 in additional funds for equipment which he deemed necessary for the new building -- manholes, shafting, pulleys, and belting. Dr. Coffman replied that such items would have to come out of the regular Station budget or be deferred. Mr. Davis expressed the view that "it will be impossible for us to carry on our operations in the new building with the budget allotments alloted to us for work in these quarters. As I understand it, the new building was provided so that we could expand our work and be of greater service to the mining people of the State".[17] Coffman replied, "It was never understood in my office that the erection of a new building carried with it any assurance that there would be an expansion of the work in mining engineering. What was understood was that you were already doing the things in the old building that you would do in the new building, but that you could do them with more room. The expansion of the work will be considered only in relation to requests that come to this office from other units of the institution. It cannot be granted as a matter of right because a new building has been erected."[18] However, the Regents Finance Committee later was more generous and granted the Station $6,000 each year for the next years for the purchase of new equipment.[19]

As he had been since 1911, the Dean of the School of Mines, William R. Appleby, was nominally the Director of the new Mines Experiment Station, but otherwise the Station was in no way connected with the School of Mines. Probably much to the disappointment of Dean Appleby, no classes were taught in the new Station until the late 1930's. The dozen full-time members of the staff, under the guidance of Superintendent Edward W. Davis, confined themselves entirely to non-educational duties, which were divided into two general classes: service work and experimental or research work.

During the twenties and thirties considerable service work was carried on at the Station for the benefit of individuals and organizations that were interested in the mineral industry of Minnesota. The work ranged all the way from the examination and identification of small samples of rock or sand to large-scale tests on carload lots of iron ore. This work was done free of charge, provided that the mineral sample had been obtained in the State of Minnesota. In each case a written report was made to the individual or organization submitting the sample. Each biennium a Legislative appropriation for State service work was included with the regular University appropriation, and came to the Experiment Station through regular University chanels.

Hundreds of small samples submitted by individuals from all parts of the State were received each year and were examined and assayed for gold, silver, copper, iron, manganese, and other valuable metal. Clay, peat, gravel, and building stones were also examined and tested.

Most of the large-scale State service test work dealt with the low-grade iron and manganese ores of the State, and several hundred tons of these materials were handled by the Station each year. After careful investigation, concentration processes were recommended, by the use of which these ore represented by the sample might be utilized and made valuable. As a result of such work at the Station, millions of dollars were invested in opening new mines and in constructing large concentration plants on the iron ranges. The amount of iron ore that was beneficiated before shipment from the State increased from 15 percent in 1920 to 40 percent in 1930. As the high-grade ores were depleted, more and more ore requiring beneficiation had to be utilized, which meant more work for the Station, since beneficiation plants could not be designed without an intimate knowledge of the nature of the ore to be treated.

In addition to the work on Minnesota samples, a certain amount of work was done on ores from other states of the Lake Superior District, as well as from the whole world. The tests on ores from outside Minnesota were made only under special agreement, depending upon the amount of work on hand and on the value of the information to be secured as it might apply to solving problems connected with State ores.

Henry Wade was primarily responsible for the State service work and he continued in these duties until Mr. Davis retired, at which time he became the Station Director. During these years Wade had a number of very able assistants, starting with B.J. Larpenteur in 1925 and ending with Harold H. Christoph.

Little State service work was done during the early years in the new building due to the confusion of moving, the reception of new machinery, and the construction of a blast furnance. During the year 1923-24 most of $6,000 which the Board of Regents had given to the Station for new equipment was spent for the purchase of material and for labor for manufacturing the equipment right at the Station. It was practically impossible to purchase on the market machinery of a size and nature suitable for pilot-scale work in ore dressing, and it was much cheaper and more convenient to purchase the rough material and to provide the labor so that the equipment could be built in the Station's own shops. The following equipment was thus constructed: several pipe launders, a cylindrical ball mill, several belt conveyors, and two experimental jigs. In addition, a Janney classifier, a Herreshoff roasting furnace, and a Dorr classifier were rebuilt during the year.[20]

A new log washer was also constructed, as inquiries had indicated that the prices being charged by the manufacturing company for log washers were excessive. The Station workers erected an eight-foot, tray-type, Dorr thickener which had been deposited at the Station by the Dorr Company of New York. The thickener was valued at about $2,000 and the Dorr Company had given the use of this thickener to the Station indefinitely. This had been quite a concession on their part and had reflected their interest in the Station's work as their organization was in a very competitive market and seldom, if ever, gave or loaned any equipment without charge.

As the laboratory equipment became more complete, it slowly became possible for the Station staff to do more State service work. During 1923-24, though only sixteen large-scale (1/2 ton or more) tests were made, over 500 small samples that had been submitted were examined and assayed. So much time and attention had to be devoted to the construction of equipment and to the installation of equipment that the Station staff had not encouraged mine operators to submit samples for tests.[21]

Little equipment was added during year 1924-25 owing to the fact that no special-equipment fund was available. The shops were busy constructing special apparatus and remodeling old machines. The Deister Concentrator Company presented the Station with a diagonal-desk concentrating table . The tables which the Station had been using were too small to operate satisfactory with the new equipment and the Deister Concentrator Company gave the Station the new table as the result of an investigation made by one of their engineers who had visited the Station some years before. This machine was the same size and design as the tables then being used in the ore washing plants in Minnesota.

In 1924 the Dorr Company, who had become quite interested in providing equipment for Minnesota ore treatment plants, proposed the substitution of bowl classifiers to replace settling boxes and reciprocation tables. To test the idea, they loaned the Station a bowl classifier. After many tests at the Mines Experiment Station, it was found that the bowl classifier could effectively remove a large portion of the fine silica from a waste ore without an excessive loss of fine iron and would deliver a well-drained concentrate. As a consequence, table treatment of washer fines was gradually superceded by bowl classifiers in Minnesota until eventually the use of tables was completely abandoned. Though this change usually did not improve the metallurgical efficiency of the plants, it did simplify them and lowered their operating costs.[22]

Fewer State service tests were made during 1925-26 than in 1924-25 due to the depressed conditions facing the iron ore operators.[23] Nevertheless, the increasing reliance upon beneficiation in the production of Minnesota iron ores brought greater and greater importance to the State service work of the Station. Different iron ore companies used the service in different ways. Some companies, when a specific problem arose, would arrange to have a specific test made upon a sample of the particular ores. Others would have different ores tested by a single concentrating device or method.

At one time, for example, Pickands Mather & Co. became interested in the possibility of improving the performance of jigs in their concentrating plants. After considerable time and a lot of testing at the Station, the rough control of the distribution of particle sizes in the jig bed resulted in improved production rates. Various types of jigs were tested and finally a jig was designed especially for the treatment of the Pickands Mather iron ores. Jigs of this design (known as Controlled Settling or Conset Jigs) were installed in two Pickands Mather plants and performed satisfactorily for the remaining life of the adjacent ore deposits. Further efforts to improve the performance of jigs continued at the Station well into the 1940's.

During the twenties Butler Brothers (now part of The Hanna Mining Company) had a group of low-grade iron ore properties in the Nashwauk District of Minnesota. Their production came from the operation of three concentration plants, the Harrison and Shada at Cooley and the Patrick at Pengilly. Butler Brothers maintained a small research staff with some small-scale testing facilities. One of the chief responsibilities of this staff was to plan the details of ore treatment well in advance of actual mining. For example, each year an ore deposit that was to be treated two seasons later was carefully drilled, sampled, and tested. If new equipment or any physical changes in the plants seemed necessary, these problems were studied. From time to time the Experiment Station was asked to make certain specific tests to help in these studies. When a tentative flowsheet had been finally chosen, arrangements would be made for the Station to make a large-scale test as a final confirmation. As a result of this cooperation between Butler Brothers and the Mines Experiment Station, Butler's Nashwauk iron ore properties continued to produce merchantable concentrates for many years.

As mentioned earlier, the Bureau of Mines had operated a small blast furnace in the rear of Appleby Hall from 1919 through 1922 with very productive results. Hence, one of the first major projects in the new Mines Experiment Station building was the construction of a new, larger, and improved blast furnace in the furnace room at the north end of the building. Before the construction of the furnace could begin it was necessary to remove about 2,000 cubic yards of dirt from the furnace room in order to lower the floor sufficiently to accomodate the additional height of the blast furnace. The lowering of the floor necessitated the strengthings of the walls, for which the Regents provided $2,000. The Superintendent of Buildings and Grounds took care of the reinforcing of the walls, but the Station staff dug and removed the excess dirt.

The new furnace was built under a cooperative program agreed upon by the University of Minnesota and the Bureau of Mines, whereby the Bureau was to design and operate the furnace and the University was to build it. The University began construction of the new blast furnace late in 1923 and completed its erection in June 1924. A very large amount of work and considerable attention by the whole staff had been required, but the resulting facilities were in excellent shape for future experimental work and little or no additional mechanical work became necessary. A piece of equipment was made available to the industries with which various problems of vital interest could be investigated at a much smaller cost than would be incurred with full-sized equipment. The furnace was 20 feet high and had a nominal capacity of six tons of pig iron per day. The Legislatures of 1921 and 1923 had appropriated a total of $20,000 for the study of the manganiferous iron ores of the Cuyuna Range, and all of it was expended in the construction of the furnace. Actually, the total cost of the construction exceeded the specially appropriated funds, but the deficit was made up from other Station budgets.

A most pressing blast furnace problem in the United States at the time was with manganese production. Steel makers and other users of manganese fully appreciated the situation in regard to domestic reserves, and realized that the United States was dependent upon other countries for high-grade manganese ore and ferromanganese. Although different grades of manganiferous iron ores occurred in several districts of the United States, the Cuyuna Range in Minnesota contained the most extensive deposits. Hence, during the following ten years the U.S. Bureau of Mines smelted hundreds of tons of Cuyuna manganiferous iron ores in the Station's furnace. They hoped to convince ore purchasers that the manganese contents of the ores were more valuable than their iron contents.

The process used by the Bureau consisted of smelting a Cuyuna ore in such a manner as to recover as much as possible of the manganese in the pig iron. This high-manganese pig iron was then charged into a Bessemer convertor in which the manganese was oxidized and removed as a high-manganese slag suitable for the production of ferromanganese. Several hundred tons of high-manganese pig iron were produced in the Station blast furnace for the eventual processing in the Bessemer convertor.

In addition to appropriations for service work at the Station, during the twenties and thirties appropriations totaling $432,000 (or about $22,700 per year) were made by the Minnesota Legislature for special research work on the low-grade iron and manganese ores of the State. When these appropriations were first made, many persons gravely doubted the necessity for such research work because the amount of high-grade ore in the State seemed to be adequate, and there seemed to be no apparent necessity for using the low-grade ores. In later years, however, the fact became generally recognized that iron ore was an exhaustible natural resource, and unless the low-grade ores were utilized at an ever-increasing rate, there would be a gradual decrease in employment on the iron ranges and a steadily decreasing tax return from the mining industry. In order for Minnesota to maintain her supremacy as an iron ore producer, new processes and new equipment had to be developed to handle the lower grades of iron ore. The entire future of the Minnesota iron ranges and of the people residing in the mining communitees depended upon the ability of technical experts to devise means by which merchantable concentrates could be prepared from the low-grade ores that existed in such enormous quantities.

By means of these special funds appropriated by the Legislature, metallurgists at the Station during the twenties and thirties materially assisted in the establishment and maintenance of a low-grade iron ore industry in Minnesota. Each year the problem became more difficult, because naturally the low-grade ores that were the most easily treated were the first to be attacked by the mining companies. Therefore, as the low-grade ores became progressively more difficult to beneficiate, the Station metallurgists had to constantly improve the existing concentration methods and to develop new processes to meet new problems. That they were successful along this line is illustrated by the fact that the Experiment Station (now the Mineral Resources Research Center) has become known wherever iron ore is mined. Hardly any iron ore deposit in the world has ever been exploited that some of its ore was not first sent to the Station for examination.

John J. Craig, Carl L. Walfred, and Charles V. Firth were generally responsible for the special iron ore research projects. Craig's assisignments usually involved some form of fire metallurgy. The size of his crew varied with the needs of the particular project. Wallfred's first assignment related to the generation of gas from peat. Other projects that followed tended to involve considerable chemistry. One of Firth's last projects related to the recovery of manganese from Cuyuna manganiferous iron ores by the application of a hydrometallurgical process.

For quite some time there had been considerable interest at the Station in the possible use of reduction roasting for the conversion of Minnesota's hematite ores to magnetite so that magnetic separation could be used for their concentration. Between 1916 and 1918 several series of bench-scale tests had been made in the Ore Testing Works, using a number of different, continuous-type roasters that were designed and built by the Station staff. Shortly thereafter a Herreshoff, seven-hearth, three-foot diameter furnace had been purchased for magnetic roasting experiments. At low feed-rates the Herreshoff furnace operated quite effectively. However, the Minneapolis coal gas used in the furnace was relatively expensive and thought was given to producing combustible gas from peat, of which there is an unlimited supply in Minnesota.

During 1919-20 the Station staff began an investigation in the Ore Testing Works of the gasification of peat. In the following year an Akerlund down-draft gas producer was secured for use. However, installation was delayed and the machine was not ready for use until late in July 1922. Meanwhile, a request had been made to the Legislature and in 1921 they made a special appropriation to the Station of $10,000 per year for two years for studies of the possible use of peat as a source of gas for metallurgical purposes. In July 1921 Mr. Carl L. Wallfred was employed to be in charge of the study. The 1923 Legislature continued its support of the project though with a decreased appropriation of $5,000 per year for the following two years. In December 1923, Mr. C.V. Firth was hired to assist Mr. Wallfred.

The gas producer was first operated in 1922 and 1923. It was then completely torn down and removed from the Ore Testing Works. No attempt was made to reassemble the machine immediately, because the Station staff wished to carry on this experimental work out-of-doors on a platform behind the new Mines Experiment Station building. In the midst of moving from the Ore Testing Works to the new building the Station staff found it quite impossible to set up the gas producer until the late spring of 1924.

Also during the summer of 1923, about 1,000 tons of additional peat was excavated from a bog near the Northwestern Terminal in northeast Minneapolis and partially air dried. Due to early rains that year, the drying was not as complete as was desired and it was necessary to store a part of the peat in sheds at the bog before the drying operation had been completed. Later, however, the Station staff respread the peat and after a month or two had an ample supply of peat for the operation of the gas producer during the following summer of 1924. The gas producer was set up outside the Mines Experiment Station building and was ready for operation by the time the peat was dry.

Until 1924 the gas producer had been operated as a downdraft machine, but in that year it was operated as an updraft machine. After the results of these experiments become available, a report was prepared during the winter of 1924-25 which included all the work done on peat at the Experiment Station, together with descriptions of the various processes then on the market for preparing gas from peat. The work at the Station had demonstrated that usuable gas could be made from peat. However, the basic problems of economically mining peat and removing most of its very high water content were not part of the study. Even to this day these problems continue to be the primary reasons why peat has not found commercial use as a fuel in Minnesota.

For ten years, from 1922 through 1932, considerable attention was given to the direct reduction or metallizing process. This process consisted in changing iron ore to metallic iron at a relatively low temperature. When this conversion had been completed, it was possible to separate the metallic iron from its impurities, after which the metal could be melted into steel of any desired quality. This was not a new process and more or less experimental work had been going on for the past fifty years along this line. As the price of fuel, labor, and transportation increased, the direct reduction process became more attractive. With the large amount of iron ore available in Minnesota, it seemed that some attention should be given to this work by the Experiment Station staff. The development of a direct reduction process would be of immense value to the State of Minnesota, as it would be possible by the use of low-grade fuels, such as lignite or possibly peat, to produce iron and steel in large quantities in Minnesota rather than to export all of the State's raw material.

Between 1922 and 1925, sufficient attention was given to various direct reduction processes to keep the staff informed on the work that was being carried on by other agencies, and also, to check up on some of the experimental data that had been published. Careful study was given to various plans for carrying on this reduction work, with the result that the staff felt capable of working out a method for metallizing iron ores of any quality in a very inexpensive manner.

The Station people working on the project were: John J. Craig, metallurgist (in charge); Carl L. Wallfred, chemical engineer; and Charles V. Firth, chemical engineer. Cooperating with them were two metallurgical engineers from the U.S. Bureau of Mines: Edward P. Barrett and Alexander Simonet.

The 1925 Legislature appropriated $30,000 for a year for the next two years for the general study of the beneficiation of low-grade iron ores and the specific study of the direct reduction process. The work of the 1925-26 year consisted in purchasing new equipment; building various metallurgical furnaces and other equipment; and conducting various tests along the lines of reduction of iron ores. Sponge iron, briquetting, heat penetration, the making of metal from sponge iron, insulating materials, high-temperature alloys, retort walls, etc. were studied. Fourteen furnaces of various types were constructed. Two furnaces were each built four times, making a total of twenty-two furnaces. This was exclusive of auxiliary equipment built in connection with the furnaces and their alterations. Nearly 600 tests were made, varying in duration from less than an hour to three days. By the beginning of 1926 a decision had been reached as to the process best adaptable to the problem, and the Station Staff immediately constructed a fairly large-scale reverberatory furnace to metallize iron ore using gas or pulverized coal for heating purposes. After several months of operation, nearly enough ore had been metallized--about forty tons--to carry on the next step in the process, namely, melting the metallized ore down and converting it to pig iron.

The operation of the metallizing furnace had been expensive. The staff had to rebuild the furnace several times and to provide labor to operate it night and day. By the first of December 1926, it was estimated, there would be only about $5,000 left in the budget. However, this would be sufficient to finish the experiment, that is, to melt down the metallized ore in the open hearth furnace. About this time, the University Comptroller notified Dean Appleby that the gas consumption at the Station was too much for the University to handle. The records showed during the past eleven months the Station had used about $4,000 worth of gas in the metallizing furnace. The comptroller said that the University budget could not carry this abnormal charge for gas and that the Station must provide for it out of their own budget. Dean Appleby replied that if the Station had to pay this $4,000 gas bill, the Station would have only $1,000 left for the completion of the experimental work. This would be insufficient. He pointed out that the University had always taken care of the gas used in the past and therefore the Station had made no provision to pay for the gas when the metallizing work had been laid out. The Station had never been asked for an estimate of gas consumption in advance and, in fact, this was the first time any matter relating to the payment of gas bills had come to the Station's attention.

Dean Appleby therefore asked President Coffman to bring this matter to the attention of the Board of Regents and to see if it would not be possible for this deficit in the University gas budget to be met in some other way than taking the money out of the Station's budget. In Appleby's opinion, the experiments were of such vital importance to the State that before paying this large gas bill from the Station's budget and thus practically stopping the work, it seemed to him that the whole matter should be brought to the attention of the University officials. The work had progressed so satisfactorily and so completely according to the program originally laid out, that Appleby believed the matter should be given careful consideration before authorizing a payment of this money out of the Mines Experiment Station budget.[24]

President Coffman was of a different mind. The amount of gas and electricity being consumed by the Experiment Station and which was being charged to the University had become a source of serious alarm. It was true that in the past an effort had been made to provide power for the Station, but it had been expected that there would be no excessive charges and that the University's allotment for these purposes would not be exceeded. President Coffman said that the Experiment Station was not entitled to draw upon University sources for more power than it had normally used in the past. The entire cost of the gas and electricity used in experimental work, particularly in those projects which were furnaced by special appropriations, should be paid for by the Experiment Station. The allowance that the University made for gas and electricity was liberal, but the University clearly could not continue to pay the enormous bills that were being incurred by the Station in recent months. For example: in July 1925 the Station consumed $62.80 of gas; in July 1926, it consumed $497.13 of gas. In August 1925 it consumed $93.60; in August 1926, $1,235.39. In September 1925, it consumed $43.99; in September 1926, $1,240.99. In October 1925 it consumed $38.32; in October 1926, $1,008.44. In other words, during the first four months of the 1925-26 year the Station consumed only $238.31 worth of gas, but during the same period of 1926 it used $3,981.95 worth of gas. The same situation prevailed with the amount of electricity consumed. During the first four months of 1925, the Station consumed $721.00 worth of electricity; in 1926, $2,289.35. The University, even if it had wished to do so, could not continue to finance the Station's experiments at this rate. During the first four months of 1926, the University had been spent for the Station nearly four times as much as had been spent for gas and electricity during all of 1926. The allotment which the University had made for these purposes, was not only liberal according to Coffman but was as generous as the University could continue to make.

President Coffman directed that the Station's experimental work should be carried on within the limits of the Station's budget. The budget really should cover all the cost. Any any rate there should be no request made to the University to finance deficits and there should be no more than the normal amount of gas and electricity consumed, as provided for heretofore in the University budget, without having the charge made directly against the Station's own experimental funds. President Coffman requested that Dean Appleby take such drastic steps at once as might be necessary to correct the situation. The Station could not continue throughout the year on the basis that the Station had proceeded. The University would do what it could to help the Station out while Appleby was correcting the situation. President Coffman offered to ask the Board of Regents to provide $3,000 out of its funds tohelp wipe out the deficit which had been created. The remainder of the deficit would have to come out of the Station's own appropriation for special research. In doing this it would be with the understanding that in the future any charge in excess of the amount that the University would normally provide for gas and electricity would be made entirely against the Station's own budget.[25]

Dean Appleby thanked President Coffman for his consideration of the request. Dean Appleby recognized that the situation was very unfortunate and began to take steps to see that it did not recur. Since the abnormal gas consumption took place in the furnace room, a special gas meter was connected in the pipe line supplying the furnace room. From then on this meter was read with the rest of the meters in the building and the Station reimbursed the University for the gas consumed as recorded by this meter. In the future all of the Station's estimates for operating costs for special or other appropriations would take into account the fact that abnormal charges for gas and electricity would have to be paid for out of the Station's own budgets.[26]

The metallized ore that was made by the initial steps of the process was of little value on account of the large amount of silica that it contained. Therefore, it was deemed necessary to use an open-hearth furnace in which the metallized ore could be melted and the silica slagged off in order to produce a marketable product in the shape of pig iron or steel. An open-hearth furnace was bought early in 1925 and was delivered in October of that year. It was a three-ton, tilting furnace made by the Wallman-Seaver-Morgan Company of Cleveland. It was 14 feet long and 6 feet in diameter and the checkerwork regenerating stove that had to be used in connection with the furnace for preheating the air required a space 14 feet long, 5 feet high, and 4 feet wide.

The original plan had been to place this open-hearth furnace in the Station's furnace room in front of and to one side of the blast furnace. This location had been chosen because it might be desirable at times to charge hot metal from the blast furnace directly into the open hearth furnace as was done in steel plants. However, erection of the open-hearth furnace had hardly begun before objections were raised by the blast furnace operators (principally Bureau of Mines) people who said that the open hearth furnace would take up so much space in the furnace room that it would not be safe for the operators to run either furnace, let alone both of them at once. It was necessary to tap the hot metal from the blast furnace and the operators objected to being in such cramped quarters that they would be unable to get away quickly if there were a slip in the furnace or some other accident during tapping. Similarly, it would also be necessary to pour the hot metal from the open hearth furnace, at which time splashing metal might be dangerous to the operators if they could not escape quickly. Attempts were made to rearrange the equipment in the furnace room so as to make the operations safe, but the consensus seemed to be that no equipment should be placed in the furnace room other than the blast furnace which was already there.

Therefore it became necessary to make plans to set up the open-hearth furnace somewhere other than the furnace room, and the only space available was in the yard on the river side of the furnace room. Plans were prepared and late in 1925 a small, brick extension to the furnace room, about 30 feet square and one story high was erected to house the open-hearth furnace. The floor of the room was of molding sand, similar to the rest of the furnace room. The cost of the annex was about $4,000, which was appropriated out of the Regent's reserve.[27]

During the year 1926-27 the staff carried on further investigations to perfect their process by which iron ores could be metallized and converted into pig iron without the use of coke. The process was carried out at a sufficient scale to give complete and definite metallurgical data and to produce about ten tons of pig iron. While the work was far from being completed, it was felt that the year's work had established the fact that it was chemically and metallurgically possible to make pig iron, or as it was called "crude iron", from iron ore without the use of coke. A very much more complete understanding of the chemistry and metallurgy involved in the various phases of the problem had been secured, and it was felt that with the new appropriation that had been made available on first of July, 1927, it would be possible to go far toward the establishment of a crude iron producing industry in the State within the following two years. The results secured during the year 1926-27 had been very promising and encouraging and it only remained to see whether or not it would be possible to put the process into commercial operation in competition with Eastern blast furnaces. The 1927 Legislature again provided special funds amounting to $33,000 per year, and during 1927-28 John Craig and his assistants Wallfred and Firth continued their direct reduction furnace tests. In addition to these men, fifteen or twenty men were employed consisting of mechanics, operators, and common laborers. Progress had been made to a point where they were beginning to make some effort to get the method into commercial operation. In anticipation of this step, the Station's reverberatory and open-hearth furnaces were operated almost continously night and day for about a year. During this time the workmen made approximately seventy-five tons of metal from Minnesota hematite, magnetite, and manganiferous iron ores.

Though considerable progress was made during 1928 along the line of producing metal from ore, there still remained an exceedingly large amount of research work to be done in connection with the production of metal of the desired chemical analysis. Therefore, during 1929 Craig and his assistants spent considerable time in connection with the control in the metal of sulfur, phosphorus, carbon, silicon, titaniumn, and manganese.

In 1930 the experiments in the production of iron from iron ore in the reverberatory furnace were continued. This continuation of the work had been provided for by the 1929 Legislature through another special appropriation of $33,000 per year. The technical staff conducting this investigation now consisted of Craig, Firth, and a new man Kenneth A. Maehl. Considerable progress was made during 1930. Methods of controlling the analysis of the metal were determined, and about 100 tons of metal were produced. The problem in 1930 had been to design a furnace to operate efficiently. The fuel consumption in the Station furnace was high, but the information being developed indicated that on a large scale the operation would be sufficiently cheap to be of commercial importance. During 1931, therefore, experimental work was conducted along the line of furnace design and construction for efficiency of operation and simplicity of control.

Craig completed his work on the reverberatory smelting furnace in 1930-32. The smelting furnace that had been developed at the Station provided means by which fine ore could be converted into crude iron without the use of metallurgical coke. Several hundred tons of the crude iron had been produced in the furnace at the Station, and fifty tons of the material had been shipped to an Eastern steel plant where it was converted into steel and rolled into standard bars.

It was thought that as processes developed for the concentration of lower and lower grade iron ores, the product that the mining companies shipped would become finer and finer. Blast furnaces would not be able to handle satisfactorily this fine ore, with the result that although this fine material might be of very high grade, it could not be shipped to the blast furnaces. This was illustrated by the fact that there were very large stockpiles of fine ore on the Mesabi Range, containing over 60 percent iron, but which were of no value at that time because of the presence of an excessive amount of fine ore.

It was hoped that by 1932 arrangements would have been completed for one of the major steel companies to construct a large furnace of this type and definitely to prove its value. Unfortunately, due to the extreme depression in the steel industry in that year, this final demonstration of the process was postponed "until business conditions improved" which did not occur until interest in the process had dissipated.

After completing his work on the reverberatory smelting furnace, Craig started an investigation of the magnetic roasting process. A portion of the low-grade ore on the Mesabi Range is magnetite. Magnetite is the oxide of iron that is sufficiently magnetic so that it can be picked up by magnetic concentration and a very high-grade concentrate can be produced. However, a large proportion of the low-grade ore on the Mesabi is hematite and is not magnetic and therefore, this cheap and simple method of concentration cannot be used for this material. It is possible, however, by roasting this hematite to convert it to magnetite. For small-scale work this is a very simple process, requiring very little fuel. However, for large-scale production such as is necessary in the iron ore industry, no satisfactory roasting furnace had been developed. In 1932 the roasting had to be done at a cost of less than fifty cents per ton, using the low-cost fuels that were available. Consequently, Craig undertook to develop a suitable magnetic roasting furnace.[28]

The work proceeded quite well and by the end of the summer of 1932 Craig had a shaft furnace in satisfactory operation that would roast about twenty-five tons of iron ore per day. He and his assistants operated the furnace for a full year studying many of the operating variables.

In 1933 an $8,000 appropriation was received from the Legislature for experimental work on low-grade ores. This money was expended during the 1933-34 year in completing the development of and preparing plans for a commercial magnetic roasting furnace. The Legislature also permitted the Station to carry over from the previous biennium a surplus of $10,000 which the Station had carefully saved from previous appropriations for the construction of a commercial furnace. With this money available, a contract was prepared between the University of Minnesota and Butler Brothers of St. Paul, owners of mining lands, which specified that the Station was to use the $10,000 in the construction of a 250-ton furnace at Cooley, Minnesota, and that Butler Brothers were to construct the ore preparation and concentration plant which would be operated in connection with the furnace. The contract also stated that at the end of the 1934 ore shipping season, Butler Brothers would have the right to purchase the furnace from the University at a cost equal to the Station's expenditure on the job. The contract was approved by the Board of Regents April 27, 1934.[29]

The work of constructing the furnace and the plant at Cooley went ahead during the summer of 1934 according to schedule. John J. Craig of the Experiment Station and R.O. Hocking of Butler Brothers supervised the construction. Cooley had been selected because a large amount of wash ore tailings had been deposited in the vicinity. The initial purpose of the plant would be to determine if the conversion of such hematite tailings into magnetic ore by roasting would permit their commercial utilization at a cost that would yield a profit to mining companies. A vast amount of ore of only about 30 percent iron content, together with other hugh piles of tailings remaining from various gravity processes by which ore had been concentrated, were (and still are) at various Mesabi Range points, and would be given commercial value if the roaster succeeded.[30]

The work that had been done during the previous biennial period by Mr. John C. Durfee of the Station staff, as a field engineer, with funds specifically appropriated by the Legislature for this purpose, showed that there was sufficient low-grade ore available on the Mesabi Range to provide an almost inexhaustible supply, providing satisfactory means for concentrating could be developed. Successful operation of the Cooley Plant would constitute a direct demonstration of the possibility of commercially concentrating the really low-grade ores of the State. How generally applicable the process might become would depend largely upon the operating cost of the furnace; this was one of the points to be determined during its operation.[31]

Unexpectedly, the furnace and plant operated with little trouble from the beginning. Under Craig's direction, the Cooley Plant ran nearly continuously during the 1934 and 1935 shipping seasons, with only minor alterations and changes becoming necessary to secure satisfactory results.

The University's interest in the plant was then sold to Butler Brothers who put the unit into commercial operation from 1936 through 1938. During its first four years of operation, the plant used oil both for heating and reduction, but during the 1938 season pulverized coal was used for fuel and water gas was used as the reductant. The total production of the plant was about 40,000 tons of high-grade ore made from material that had previously been rejected as worthless. Regretfully, though the process was successful technically, it did not work out commercially because the fuels available at the time made the cost too high.[32]

Between 1926 and 1930 a portion of the Station's pilot-plant space was used by the Bradley-Fitch Company as a special research problems involving the leaching of Cuyuna Range manganiferous iron ores. The company installed and operated at their own expense a very efficient experimental plant and worked many months perfecting a leaching process. Subsequently the staff of the Mines Experiment Station were called upon to examine the process carefully, to make a trial run, and to report the results to the Federal Government.

Early in the Great Depression, when very little iron ore was being shipped from Minnesota, the Station looked around for new uses for iron. For some time in England, France, Belgium, and Switzerland, pavements made of separate, cast-iron blocks, square or rectangular had been gaining favor for use in places of particularly heavy wear. They were reported to be more durable than any other type of paving and to cost only a little more than pavements made with brick. Mr. Davis was intrigued by the reports and published several articles in technical journals recommending the adoption of cast-iron pavement in the United States. He pointed out that it would create a new outlet for Minnesota iron ore and might lead to the erection of smelters in northern Minnesota.

Cast-iron pavements would also make the erection of magnetic taconite plants more feasible.The history of iron mining in Minnesota had shown that the annual demand for iron ore fluctuated greatly, and whenever the future possibility of taconite processing was discussed, the extreme variability of the annual requirements posed a serious problem. To allow expensive taconite plants to lie idle during periods of low demand would be uneconomic, but if the Government would purchase and install cast-iron paving blocks during such periods, the plants would be able to operate continuously.

In 1932 under Mr. Davis' direction and that of Mr. W.F. Holman, supervising engineer, an experimental strip of cast-iron pavement was laid on the Campus at the foot of the Pleasant Street hill between Washington Avenue and Appleby Hall.[33] The pavement held up well and in the following year the State Legislature appropriated funds for further study of cast-iron pavement.

A number of differently shaped blocks were cast providing various types of ribs, studs, and other corrugations in their surfaces. To determine which type of surface would provide the best grip for the wheels of rubber-tired vehicles, a special testing machine was designed by Elmo E. Hanson, a technical physicist on the Station staff, and was built at the Station. The machine measured the following characteristics of the iron paving blocks: (1) the coefficient of friction between the paving blocks and rubber tires for straight skidding and for sideways skidding, (2) the stopping distance of a car on such a pavement, and (3) the tire noise. The machine consisted of two six-foot flywheels, on the periphery of which were bolted the paving blocks to be tested. An automobile was mounted such that its front wheels rested on the flywheels. The flywheels were rotated by a 15-horsepower motor to top peripheral speeds of 60 miles per hour. Hydraulic traction dynamometers were connected to the center of gravity of the car and served to measure the braking force and the sideways force when the brakes were applied or when the front wheels of the car were turned through an angle. A high-speed motion picture camera was used to record the dynamometer readings, the time, and the motion of the flywheels and of the front wheels of the car.

By means of this machine, the strengths with which both new and worn automobile tires gripped surfaces of various kinds at various car needs were measured. It was found, for example, that by changing the design of the surface pavement corrugations, the coefficient of friction could be changed by more than 100 percent. Different cast-iron surface designs similar to the tread designs on automobile tires were investigated with the idea of developing a surface that would be permanent, easily cleaned, pleasant to drive on, and as nearly skid-proof as possible. Much interesting and valuable information was secured from this investigation and eventually fundamental design principles were determined, making possible the construction of cast-iron paving blocks of a type well suited to automobile traffic.[34]

During 1936-38 tests continued in the development of satisfactory types of cast-iron blocks for streets and highways. Another experimental pavement about one-half block long was laid in two stretches on Pleasant Street on the Campus, on which skidding tests were made. The tests were repeated later to determine the effect of a year's service. Some changes were made in both of the experimental stretches of pavement in order to study certain characteristics that could not be investigated in the laboratory.[35]

The experimental studies relating to iron paving resulted in relatively few conclusions. A design was established for the base of the block that would be strong, simple to make, easy to install, and having a real tendency to become anchored in place. A slightly differently shaped base that was a little easier to cast was found to be almost impossible to keep in place. Many types of surface designs were tested. Two particular designs seemed most practical. One was best for situations having heavy but slow traffic, such as busy city-street intersections, and the other was more suitable for high-speed highway conditions.

The 1939 Legislature appropriated funds for the construction of a test section of highway, and that fall the Minnesota Highway Department laid a half-mile stretch on Highway No. 53 near Eveleth. The Mines Experiment Station was not involved in this final project. A deplorable error occurred somewhere along the line with the result that the blocks that were provided for the highway were of the design that tests had shown would not remain in place. As a consequence, the blocks came loose and became a traffic hazard. The Highway Department was soon forced to repave the test section with concrete. It was an unfortunate end to a most interesting study.[36]

During the 1930's a mining engineer named Victor Rakowsky living in Joplin, Missouri, became interested in trying to develop a heavy density method for the concentration of low-grade ores. Heavy density separation, or sink-and-float as it is sometimes called, is an ore concentrating process in which a heavy powder is mixed with water and maintained in suspension so that the suspension has a density midway between that of the waste or gangue minerals in an ore and that of the valuable or ore minerals. The lighter gangue minerals float to the surface of the suspension where they can be skimmed off, and the heavier ore minerals sink to the bottom where they can be withdrawn. During the years of his preliminary studies, Rakowsky stopped several times at the Mines Experiment Station to discuss his progress and his problems.

One day in the Spring of 1937 during a visit to the Station, Rakowsky said that he finally had a workable process and was wondering how to have the process tested on a semi-commercial scale. Henry Wade suggested that he contact Mr. Emmett Butler of St. Paul. It so happened that Butler Brothers had just started the construction of a temporary jigging and tabling plant near Ironton on

Cuyuna Range to treat the remaining tonnage of ore in the Merritt Mine. An agreement was worked out between Butler Brothers and Rakowsky that resulted in the installation of a sink-float test unit in the plant to operate in parallel with the jigs and tables using a part of the same feed ore. The plant operated during August and September 1937, by which time the small ore deposit had been exhausted.

Plans were made to dismantle the plant, but before this was done, Butler Brothers decided to check the performance of the Rakowsky sink-float unit on a Mesabi low-grade ore. The Mines Experiment Station was invited to witness the test, to suggest sampling arrangements, and to prepare a report of the metallurgical results. Eventually the test was made as planned with Henry Wade representing the Station. The feed to the plant was the same as that being fed to the Harrison washing plant then operating near Nashwauk. During the test the sink-float unit appeared to work very satisfactory.

During the entire summer's operation, the high-gravity powder used to produce the heavy-density suspension was galena concentrate which had been purchased for the work at a considerable cost. Until the final plant clean up was completed, it had been impossible to estimate the cost per ton of sink-float concentrate to be charged for the galena concentrate. The loss of galena was determined to be much greater than expected, and the cost was prohibitively high.

Galena had many desirable properties for the purposes of the process, but it was not very resident to abrasion. The circulation of the galena through the pumps and piping caused it to break down into a slime which was easily lost.

When all the data from the test was available, Mr. Wade prepared a report of the results. He had little enthusiasm for writing a report on an interesting method for concentrating iron ore, but which appeared to be too costly to be commercial. After mailing out the report, however, he decided that the method was encouraging enough to justify some further investigations.

Obviously a material more resistant to abrasion these galena was needed. It also seemed that a magnetic material that could be effectively recovered by magnetic separating equipment would be desirable. These considerations suggested something like cast iron. Hence, a little cast iron was ground to a powder and mixed with water. The resulting fluid mixture seemed to have essentially all of the desired properties, and a beaker of the fluid mixture was allowed to sit overnight. The next morning it was found that the iron had oxidized almost completely into a red,pasty mass that was only weakly magnetic.

Wade knew that high-silicon ferrosilicon was resistant to oxidation, but that its specific gravity was less than that of cast iron and that its magnetic properties were also quite different. He made a list of the desired physical properties and began to look for an available commercial ferroalloy that had properties similar to those on his list. Professors Dowdell and Joseph each mentioned to Wade a ferrosilicon containing about fifteen percent silicon that was being made at two small blast furnace plants. Some of this material was obtained, and the Station began a testing program as a State service project. The results of the tests at the Station were so encouraging that in the Spring of 1938 Butler Brothers installed a small sink-float unit using ferrosilicon in one of their Nashwauk washing plants. Later the unit was enlarged to full commercial size.

The heavy-density method of iron ore consultation soon became a widely used procedure for treating certain types of Mesabi ores. Very fortunately the method was developed just prior to the heavy demands placed on Minnesota's iron ore industry just prior to and during World War II.

In the middle 1930's it had become clear to the University faculty that steps had to be taken to bring the various divisions of the University into closer relationship with each other. The smaller the administrative unit, the more restricted the field of learning; the greater the isolation, the greater the intolerance and narrowness of those being trained in it. In the opinion of the Regents, departmentalization and college autonomy were preventing the recognition of the broader relationships that were fundamental to any training program.

As far back as 1919 President Marion L. Burton had advocated the creation of an Institute of Technology consisting of the College of Engineering and Architecture, the School of Chemistry, and the School of Mines and Metallurgy. The Board of Regents had subsequently gone part-way. They voted to correlate the administration of the College of Engineering and Architecture and the School of Chemistry under one administrative head, with the understanding that they would give consideration at some future time to the placing of the School of Mines and Metallurgy under the same head.

The arguments that had been advanced by President Burton for the consolidation and unification of the three schools into one organization were even more valid in 1935 than they had been in 1919. The interests of the three schools were similar; their work was becoming more and more integrated; they all lay in the general field of technology; their curricula were based on mathematics and physical sciences. The general objectives of the students were similar in many respects and the teachers and supervisors were concerned to a very large extent with related fields.

Following the retirement of Dean Appleby of the School of Mines, who had long opposed the consolidation, the Regents created the Institute of Technology on October 19, 1935. The Regents' action amalgamated all the branches of technical instruction and research of the University into a single unit embracing the College of Engineering and Architecture, the School of Chemistry, and the School of Mines and Metallurgy, including the Mines Experiment Station. Professor Samuel C. Lind, who had been Director of the School of Chemistry since 1926, was appointed Dean of the new Institute.[37]

Under the stimulus of Government "pump priming", more iron ore -- over 49 million tons - - was shipped from Minnesota during the summer of 1937 than in any previous year. The mining companies, accordingly, were very interested in developing new reserves to replace the ore that was being mined. The Mesabi Range had reached a state where additional ore reserves could be secured only be developing methods for concentrating the deposits of intermediate-grade (35-45 percent iron) ore. During the fall and winter of 1937-38, the mining companies shipped to the Station over twenty carloads of such ore. The staff was kept busy all winter determining the concentrating procedures for these ores. Methods for producing concentrates were developed for most of the ores, and it was hoped that a number of new beneficiation plants would be constructed on the Range in the Spring of 1938. However, business conditions turned for the worse, the amount of ore required was small, and only a few new installations were built.[38]

After a poor year in 1938 (less than 15 million tons), in 1939, thirty-three million tons of iron ore, an average amount, were shipped from Minnesota; but the 1940 season gave every indication of being one of the largest in history. The war in Europe began to be felt in the United States. Since the amount of ore produced from underground mines and from concentration plants could not be quickly expanded in times of abnormal demand, the strategic importance of the great Mesabi open-pit mines could hardly be overestimated. Though it was realized that Minnesota, if necessary, could produce fifty million tons of iron ore per year for ten years without any great expenditure for new equipment and without any great increase in the amount of labor required, by that time a number of the steel companies would have completely exhausted their ore reserves.

It was for this reason that much interest was being shown by many of the iron ore producing organizations in the development of new sources of iron ore. Geologists were searching all territory adjacent to the Great Lakes for new ore reserves. The high-grade direct shipping ore was nearly all controlled by a few of the largest companies and, therefore, new ore reserves could only be developed by utilizing lower-grade ores.

During the winter of 1939-40 the mining industry again made great use of the facilities that the Station had to offer. About six hundred tons of ore samples were submitted by the mining companies, and, as a result, four new concentration plants were projected for construction in the spring of 1940. Due to a reduction in ore prices, the construction of two of these plants was deferred, but the other two were constructed and soon began to produce concentrate.[39]

CHAPTER 3 - THE TACONITE YEARS

The twenty-one years from 1941 to 1962 can be called the taconite years because during that time the Station devoted most of its energy to the problems connected with the utlization of taconite, the low-grade, iron-bearing rock that occurs in enormous qualities in northern Minnesota. During the first half of this period the Station worked on the problems of concentrating and agglomerating the magnetic taconites. During the second half the Station was involved in the study of the nonmagnetic taconites. The work on taconite was slow in starting, however, and during the early forties the problems produced by World War II were of great concern to the Station.

In 1940 the threat of involvement in the War in Europe revived America's interest in the low-grade mananiferous ores of the Cuyuna Range. High-grade manganese ore is one of the most important of the strategic minerals that do not occur in the United States in sufficient quantities for its own requirements. Most of the Nation's supply of high-grade manganese ore is imported. On the Cuyuna Range of Minnesota great quantities of low-grade manganese ore exist, and shortly after World War I a process was developed at the Mines Experiment Station by means of which high-grade manganese concentrate could be made from the low-grade Cuyuna Ore. However, during the twenties and thirties the prices of imported high-grade manganese ore had been so low that little or no profit could have been made by the processing of Cuyuna ore, had a suitable plant existed.

By 1940 the prices that the Federal Government was paying for strategic supplies of high-grade manganese ore had increased to such an extent that it was thought that the Cuyuna ore could be concentrated profitably. In addition, the supplies of overseas manganese ore were being diminished due to the war in Europe. Since no private organization could afford to construct, simply as an emergency measure, the large concentrating plant that would be necessary to utilize the Cuyuna ore, attempts were made in 1940 by several Minnesota mining companies to interest the Federal Government in financing a plant and in contracting for the output. Being in a position to give technical direction to such an undertaking, the Mines Experiment Station stayed in contact with the Government and with the Minnesota companies. It was evident that such a development would be of great importance to Minnesota, especially to the people on the Cuyuna Range.

During 1940-42 the Station made several investigations for the War Production Board, and, as a result of this work and that of other agencies, the Government for a time planned to construct a $20-million manganese plant on the Cuyuna Range. Before the plant could be started, however, the sea lanes were reopened and the importation of foreign high-grade manganese ore was resumed.[1]

The declaration of war in December 1941 brought increased service work to the Station: eighty large-scale and nearly two thousand small-scale tests were made during the following year, and the pertinent reports were submitted to the respective mining companies.[2]

As the war lengthened, its effect was felt by the employees of the Station. The staff then consisted of six engineers and fifteen machinists mechanics, and laborers. During 1943-44 it became very difficult to maintain the non-technical staff at full working strength because of the high pay-scales being offered by industrial plants. Without a doubt, the University retirement, insurance, and hospitalization benefits were very important during those years in holding the older employees. Work was slowed down due to the loss of the younger men, because it was impossible to replace many of them. Notwithstanding this handicap, nineteen carloads of ore samples were tested during 1944, and the mining companies submitting these were given reports indicating the methods that could be used for benefication.[3]

With the end of the War, the employment situation at the Station improved considerably. A scientist, Mr. Leslie S. Taylor, and an associate scientist, Mr. William D. Trethewey, were added to the technical staff.[4] However, the sudden death of Mr. Charles V. Firth, who had been at the Station for twenty-two years, was a severe blow.[5]

During the ensuing years though a few mining companies continued to submit samples of intermediate-grade ore for beneficiation tests by gravity methods, several of the major mining companies were now deeply involved in taconite concentration. Hence, the State service work of the Station was largely connected with that type of investigation. However, State service work continued on small samples. During 1945, for example, nearly seven hundred such samples were examined and reported to the parties who had sent them in.

As mentioned in the first chapter, Edward Davis had begun to study the taconite problem soon after he had arrived at the University. Between 1912 and 1915 he had invented a magnetic tube for determining the iron content of taconite samples and a magnetic log washer for concentrating large quatities of the rock. On leave from the University between 1916 and 1918, he had directed the operation of a 100-ton per day experimental taconite plant in Duluth. Later, he had served as a consultant to the Mesabi Iron Company during their operations of a taconite plant at Babbitt in 1922-24.

Between 1924 and 1940 very little research work on Minnesota taconite was done at the Station, other than an occasional test with the magnetic tube or the small log washer, simply because there was no material to work with. However, from time to time the Station conducted tests on magnetic ores from other states and from foreign countries. By so doing the staff were able to maintain their skills in magnetic concentration.

The demise of the Babbitt plant had not discouraged Davis. For the next twenty years whenever he contributed an article about iron ore to a publication, he concluded his writing with a strong plea for the utilization of the magnetic taconite of the Mesabi Range.

The iron ore companies, however, were not interested. The Minnesota ad valorem tax was the big stumbling block. Since to make a ton of taconite concentrate required three tons of taconite crude, any company going into the business would have to acquire enormous reserves. If these reserves were taxed in the same manner as the richer hematite ores, the enterprise would become uneconomic.

Then in 1939 Davis wrote an article for a monthly bulletin circulated among Minnesota public officials, pointing out that the tax law as applied to taconite was suicidal. He said that he was convinced that the steel companies intended to strip the Mesabi and then turn to foreign ore sources, thus dooming the Lake Superior district. He warned that a war would just about exhaust the Mesabi's once "limitless" ore resources of high-grade ore.

The article was well timed. The Junior Chambers of Commerce of Hibbing, Duluth, and five other communities had just organized a Northeast Minnesota Rehabilitation Committee. They too were anxious about the future. Davis was invited to address a forum of Jaycees from the seven towns. The audience as a whole received him with customary indifference, but three men who were members of the Junior Chambers' new committee listened intently. They took Davis into a back room and continued the discussion until after midnight. It was the beginning of a change.

Two years later, with constant patient persuasion from Davis, the Junior Chambers of the Range endorsed Davis' arguements. With great courage they sponsored a new tax bill in the legislature, which was passed in 1941. The law placed a tax of about six cents a ton on taconite processed and shipped but exempted the value of holdings in the ground. Equally important, it excluded from tax all capital investment in taconite production.

Most of the Range folk thought the law was outrageous, and argued that talk about depletion of the rich direct shipping ores was a bogeyman created by Davis to scare them. They had heard gossip for years that the big companies were hiding from the tax authorities vast deposits of high-grade ores which they would "discover" as needed.

They soon learned otherwise. Within three months two hundred prospecting permits had been filed, compared with two in the previous four years, and in a year many of the best taconite deposits had been claimed. This activity, which significantly uncovered no new direct shipping ores, at last convinced the citizenry that the direct shipping ores were close to exhaustion.

Bethelehem Steel Corporation and American Rolling Mills leased large areas of land containing taconite and began actively working these properties hoping to develop methods for converting this material to high-grade ore. The Mines Experiment Station began working closely with these companies and others on the technical problems involved, because the importance to the State of the successful development of a taconite industry could hardly be overemphasized.

Hundreds of tons of taconite were shipped to the Station for experimental purposes. The basic flowsheet for taconite concentrations had been worked out twenty years before. It remained now only to refine the process by improving grinding techniques and substituting magnetic drum separators for magnetic log washers. The agglomeration of the fine concentrates, however, remained a nagging problem well into the 1950's. The Station tried many procedures (briquetting, nodulizing, sintering, extrusions) before settling on the balling and pelletizing process developed by Charles Firth before his death. In the late forties the Firth process was taken over by Pickands Mather and Company at Hibbing, who soon had a shaft furnace in operation.[5]

From December 1945 until June 1958, L.S. (Sam) Taylor was the prime researcher in pelletizing at the Mines Experiment Station. He conducted bench-scale experiments in balling and pelletizing, investigated numerous binders including starches, binders, bentonite, and other clays besides large-scale tests in shaft furnaces and on a traveling grate.

Meanwhile, State service work went on as it had been for the past forty years. Hardly a day went by when there was not a visitor seeking help of some sort. He might be an individual who had picked up a curious rock on a recent fishing trip, or he might be the chief engineer or operations officer of one of the major Minnesota mining companies. Each visitor was received with the same courtesy and attention. His sample, whether it weighed a few ounces or many tons was thoroughly examined, tested, and reported in writing. If the sample had been obtained in Minnesota, there was no charge.

During 1942-44 Charles Firth of the Station staff had developed a process for producing iron powder from iron carbonate slates of the Mesabi Range. However, he had not been able to perfect the process before his death. In October 1946 Eugene R. Bundul was hired to reactivate the project. In December 1947 the process was taken over by Continental Machines Company, Inc. of Minneapolis, who built a five-ton iron powder plant near Aurora, Minnesota. The plant, which was financed by the Iron Range Resources and Rehabilitation Commission at a cost of about $650,000, operated intermittently for about a year under the name of Iron, Inc., and was managed by Mr. Bundul, who was on leave from the University.

By the late forties the commercial development of taconite beneficiation was well under way on the Mesabi Range. The Reserve Mining Company had resurrected the old plant of the Mesabi Iron Company at Babbitt and Pickands Mather and Company were operating a pilot plant at Aurora. The first shipment of taconite concentrate pellets was made in the fall of 1948.[6]

Early in 1948 the blast furnace at the Mines Experiment Station was operated in cooperation with the Reserve Mining Company, smelting taconite pellets for the first time for the production of pig iron. Initially, the burden consisted entirely of natural ore and was changed in steps until it consisted entirely of pellets. During the conversion from natural ore to pellets, the capacity of the blast furnace was increased from about six tons pig iron per day to nearly twelve tons per day. The month-long blast furnace operation was very successful and, in all, about one hundred and fifty tons of pig iron were produced from this new taconite product. Small souvenir castings were made of the first iron produced, and then were distributed to about two hundred persons who had made significant contributions to the Minnesota taconite program.

During the biennium 1948-50, research activities that were largely connected with taconite continued as the major effort of the Station. A third large company, the United States Steel Corporation, became interested in the erection of a taconite plant. In fact, it was said that more progress toward the establishment of a taconite industry was made in 1949 than in any other year in the past.

In 1949, as Mr. Davis began to spend more time on taconite developments and less time on routine Station matters, Mr. Wade was advanced from Scientist to Assistant Director. In 1951 Mr. Davis gave up the directorship and took a one-year leave of absence to help Reserve Mining Company in the re-construction of the Babbitt Plant. Mr. Wade then became Acting Director. From 1952 through 1954 Davis was a part-time professor at the Station and a part-time consultant for Reserve. When Reserve began the big plant at Silver Bay in 1955, Davis retired from the University, moved to a new home at Silver Bay, and served the rest of his life as a consultant for Reserve. He died in 1975.

By 1950-52 the taconite problem had reached a stage where important commercial developments were being taken. It was felt, therefore, that while the Station should continue its important service in taconite development, it should also concurrently develop a basic research program for the future, and projects were being supported by the Station both in the School of Mines and in the Department of Electrical Engineering with a view to developing new fundamental subjects. With the development of the taconite industry, the Station shared responsibility with the School of Mines for supplying the need for highly trained people and a close working relationship was being maintained in that direction.

Electrical Engineering assisted in the study of the magnetic properties of the oxides of iron and the School of Mines and Metallurgy assisted in the study of the fundamentals of ore flotation. Both of these vital researches eventually became of the greatest importance in the subsequent taconite industry. An important contribution of the Mines Experiment Station was the establishment of a taconite scholarship fund contributed from private sources to encourage the training of engineers for the special operations which the future expansion of the taconite industry would demand.

Although the Station had been able to pelletize taconite concentrates in a shaft furnace and Pickands Mather were using a shaft furnace in their experimental plant, the operation of a shaft furnace was not without its problems, and other methods of agglomeration were being studied by iron ore companies. For example, the U.S. Steel Corporation was experimenting with sintering and nodulizing.

Between 1951 and 1954 the Mines Experiment Station made many pelletizing tests on a Bros stoker that had been modified at the Station for use as a traveling-grate pelletizing machine through a cooperative agreement between Pickands Mather and Company, the Reserve Mining Company, and the University of Minnesota. The machine was about sixteen feet long and a little over two feet wide. It had a capacity of about three tons of pellets per hour. Pickands Mather and Reserve supplied taconite concentrate to the Station from their experimental plants at Aurora and Babbitt, Minnesota, for the tests, which entailed many months of work. Each test required two or three eight-hour days by a work force of a dozen men. Although the actual pelletizing required only one day, one or two days of work were necessary to prepare the various materials.

A test involved first placing a three-inch layer of burned pellets on the grate. After this layer had been heated by a gas flame, a three-inch layer of "green" (unburned) balls dusted with pulverized coal was placed over it. Above this so-called ignition layer, two seven-inch layers of green balls dusted with considerably less pulverized coal were consecutively added. As the grate moved slowly along, the balls were heated by the burning of the coal placed upon them. The combustion was supported by an updraft current of air.

After many months of tests at the Station, Reserve went ahead with a traveling-grate system when they built their new plant at Silver Bay, Minnesota in 1955. Pickands Mather, on the other hand, remained with shaft-furnace pelletizing in their Hoyt Lakes plant which was completed in 1957.

At the conclusion of the tests for Reserve and Pickands Mather, numerous tests were made for The Cleveland-Cliffs Company. Cleveland-Cliffs was considering plants at Humboldt and Republic, Michigan, for the concentration by flotation of low-grade iron ores in which the iron was presently largely in the form of the mineral specularite. The concentrate had to be agglomerated prior to shipment and various types of equipment were being considered for these operations.

Since the tests were made for Reserve and Pickands Mather had preceded the tests made for Cleveland-Cliffs, agreements were made to let the Reserve and Pickands Mather use any improvements that might come out of the tests for Cleveland-Cliffs. Since tests made for Reserve and Pickands Mather were on Minnesota ores, they had been made without charge. However, it was necessary to set up a special budget for the Cleveland-Cliffs tests on Michigan ores. Charges for services, general supplies, and other expenses were then made against this budget. An item for overhead (light, heat, water, general maintenance, office supplies, and secretarial wages) equal to forty-six percent of the charge for services was added.

Several hundred tons of pellets were successfully made for Cleveland-Cliffs by the traveling-grate process. About fifty tons of the pellets were shipped to Michigan for further study. The results led to the development of Michigan's first pellet plant at Eagle Mills in 1956, employing a straight-grate process. Cleveland-Cliffs later built grate-kiln systems at Humboldt in 1960 and at Republic in 1961.

The tests at the Station indicated that the commercial pelletizing of iron ore concentrate on an up-draft, horizontal-grate, pelletizing machine was feasible. Either magnetite or hematite concentrates could be pelletized though the hematite concentrates required slightly more coal. The process could be accomplished on a modification of either a standard sintering machine or a stoker.

Another reorganization of the Mines Experiment Station and of the School of Mines took place in 1957. In May of that year, the Dean of the Institute of Technology, Athelstan Spilhaus, recommended to President Morrill that the Mines Experiment Station, which had been operating directly under the Institute, be made a unit of the School of Mines. President Morrill concurred and on July 1 the Station again came under the School of Mines as it had been twenty-odd years before. Dr. Strathmore R.B. Cook was named head of the School of Mines and therefore had over-all charge not only of the School but also of the Mines Experiment Station. Henry Wade became Director of the Station. In order to ensure close cooperation in teaching and research, Wade, Christoph , and Trethewey of the Station staff began to participate in meetings of the School of Mines faculty.

While the Reserve Mining Company, Pickands Mather and Company, and the United States Steel Corporation were proceeding by leaps and bounds toward the commercial exploitation of their deposts of magnetic taconite, The Hanna Mining Company seemed to be falling behind in these new developments. Their iron ore reserves lay mostly in the western Mesabi, and geologists had said that only in the eastern Mesabi were there extensive deposits of magnetic taconite. West of Mountain Iron, geologists said, the influence of the

Duluth Gabbro had been ineffective and the taconite remained the nonmagnetic variety. Hanna therefore decided to assess their nonmagnetic reserves through an extensive drilling program and to take a hard look at magnetic roasting followed by magnetic separation to concentrate these materials.

Upon the urgings of The Hanna Mining Company, the staff of the Mines Experiment Station returned to their studies of magnetic roasting which had been dormant for many years. In the late thirties, after the Cooley magnetic roasting furnace had been dismantled, the Station had installed a shaft furnace of approximately one thousand pounds capacity for magnetic roasting. The Station shaft furnace had been built to operate somewhat like the Cooley furnace, but it was not a convenient test unit and was soon torn down. In the early fifties the Station had only two small pieces of apparatus for magnetic roasting. Both were batch drum furnaces. The first roasted only a quarter-pound of ore at a time, and the other would handle only a twenty-pound charge. The Bureau of Mines had a duplex rotary kiln that had been used a few times for magnetic roasting. It was quite large and awkward for laboratory use and had a low capacity relative to its size. Actually, it consisted of two kilns: a large kiln used for preheating the ore and a smaller kiln for reducing (magnetic roasting) the discharge from the first kiln. Solid fuel such as lignite char was ordinarily used as the reducing agent in the second kiln. When the temperature and the fuel were carefully controlled, good reduction was obtained in the Bureau's kilns, but the rate was low and the heat economy was poor.

The lack of a high-capacity, continuously operating furnace for magnetic roasting led Dr. Norman F. Schulz of the Station staff to convert the traveling grate pelletizing machine to a magnetic roaster. During the late 1950's a number of tests were conducted by Dr. Schulz on several low-grade Minnesota iron ores in an effort to develop such a roaster for large-scale commercial operation. At the conclusion of the tests, the magnetic roasting on the horizontal traveling grate appeared to be technically and economically feasible. The process was developed as a normal function of the Station and the project was supported in large measure by funds provided by the Iron Range Resources and Rehabilitation Commission.

The roaster was essentially an apparatus in which the iron ore, properly prepared by comminution and agglomeration, formed a continous gas-permeable bed of uniform cross section which was carried through a series of treatment zones on an endless, heat-resistant, permeable conveyor. Gas mixtures of controlled temperature and composition were forced vertically through the ore bed, successively drying, heating, reducing, and cooling the ore in a continous process. A combustion chamber, which was fed a mixture of air and natural gas and which supplied both heat and the reducing gas mixture, was an integral part of the apparatus. Auxiliary equipment included a gas cooler, gas blowers and ducts, ore preparation and handling equipment, and instrumentation and control devices.

Proving the operation of the experimental horizontal traveling grate roaster was complicated by the fact that performance was largely dependent on widely variable properties of the raw ore. Thus, the composition and physical structure of any given ore dictated a particular set of conditions for roasting which was optimum for that ore. In addition, the particular details of treatment during the subsequent magnetic procedures could also have some effect on the exact position of this optimum during consideration of the overall process. On the other hand, considerable latitude in roasting conditions was available in the traveling grate roaster, so any overall metallurgical test from raw ore to iron ore concentrate, through roasting and magnetic separation, was more a test of the ore than of the traveling grate roaster.

In view of the variation in the ores and in consideration of the lack of knowledge concerning optimum operating conditions of both the roasting process and the magnetic separation procedures, large-scale tests were not stressed during the investigation. Instead, many tests were made on a few typical raw materials, in which operating conditions were investigated and the quality of the products obtained was determined by assays and magnetic tube tests on selected samples of product.

The operation of the experimental traveling grate roaster showed that the apparatus could readily produce the conditions of temperature, time, and reducing atmosphere required for the continous magnetic roasting of iron ores. The apparatus also appeared to be applicable to the pre-leach roasting of certain manganiferous ores because the roasting conditions could be controlled within very narrow limits. Most crude ores, when crushed to minus 1/2 inch or less, could be balled and roasted without further preparation. Dust handling problems were negligible since the ore fines were tightly bound in the balled feed.

By a queer twist of fate, the concurrent extensive drillings of The Hanna Mining Company, which had inspired the magnetic roasting tests at the Station, uncovered not only nonmagnetic taconite, but large deposits of magnetic taconite. Today these deposits provide the feed for Hanna's National Steel Pellet Plant at Keewatin and Butler Plant at Nashwauk.

A major research effort of the Station between 1956 and 1962 became known as the Great Northern Project. Although its results and findings caused no stir when the Project ended, in time to come it is safe to say that they will be intimately consulted by people assessing the non-magnetic reserves of the Mesabi Range.[7]

The Project began quite informally in 1955 at a Minnesota Alumni reunion, when a Mr. A.J. Haley mentioned to Henry Wade, the Acting Director of the Station, the possibility of the Great Northern Railway Providing some assistance to the efforts of the Mines Experiment Station toward the development of means for utilizing the nonmagnetic taconities of the western Mesabi. Mr. Haley was then director of the Mineral Research and Development Department of the Railway. Though Wade's reaction was favorable, Haley asked him not to say anything further about it until he had explored the idea with his company's directors. If their attitude were encouraging, he would try to develop something.

In those days the Great Northern Railway Company had, and its successor, Burlington Northern, Inc., still has, lines of railroad serving the Mesabi Range in Minnesota. In the past the railroad had transported and was then transporting large tonnages of ore from the Range to docks at Lake Superior. The Company officials were aware of the fact that the reserves of direct shipping iron ore and of easily concentrated iron ore on the Mesabi Range were limited, and they anticipated that the amounts of these ores available for transportation would decrease in the years to come. The officials recognized, however, that there were large quantities of nonmagnetic taconite in the territory served by the Great Northern, and it was in the interest of the Great Northern that a means of producing iron ore commercially from the nonmagnetic taconite be developed and perfected. Likewise, it was to the interest of the people of this territory and to the economy of the state of Minnesota that this natural resource be developed.

As a result of Mr. Haley's efforts, in May of 1956 the directors of the Great Northern Railway determined to cooperate with the University of Minnesota in a research project at the Mines Experiment Station for the purpose of exploring and developing, if possible, a means for the commercial use of nonmagnetic taconite. The formal contract was signed in October. Originally set for three years, at a cost to Great Northern of $40,000 per year, the project was later extended for an additional three years. The funds granted by the Great Northern made it possible for the Station's staff to allocate a great deal more time and study to the problem of nonmagnetic taconite than would otherwise have been the case.

To the end that the western Mesabi Range would continue as a major supplier of iron ore, the research was designed to investigate the occurrence, the nature, and the concentrating characteristics of the various types of nonmagnetic taconites present in the Range west of Virginia, Minnesota. Investigative emphasis would be placed on the segment of the Mesabi Range between Prairie River and Buhl-Chisholm. To the west of Prairie River, the iron formation becomes markedly thinner and is more steeply dipping. To the east of Buhl-Chisholm the magnetic taconites become dominant. Specifically, the objectives of the project were to:

1. Investigate the mineralogy and mineral associations of the nonmagnetic taconites so as to be able to classify the various types.

2. Determine in a broad way the areal and stratigraphic extent of each type of material.

3. Determine the concentrating characteristics of each type.

4. Determine and demonstrate the relationship between mineralogic characteristics and concentrating characteristics.

5. Investigate beneficiation processes that appear to be best adaptable to the concentrating characteristics of the taconites.

Initially, the Great Northern Railway Company established a fund with the University business office by an a starting deposit of $10,000. The Station then charged expenditures against this fund. Every three months the University sent the Great Northern a statement and the Great Northern then reimbursed the fund by the amount of the expenditures. Although the Station was authorized to expend up to $10,000 per quarter, it was not necessarily intended that the Station spend the entire amount. Their representative, Mr. David Gleason, kept in close touch with the work and was normally consulted regarding the employment of people or for any unusual expenditure for equipment or supplies.

To get the project started, it was deemed desirable to gather as much information as possible as to the nature of the iron-bearing materials of the western Mesabi. Many years before, a great many exploration holes had been drilled in the area, most of which had been drilled for the purpose of finding either direct shipping or gravity concentrating ores. In much of this exploration, relatively little attention had been given to the problem of learning the detailed nature of the nonmagnetic taconites. Dr. J.W. Gruner of the University's Department of Geology and some of his associates had from time to time examined a great many of these drill samples and the results of their studies had been summarized in various publications. However, Dr. Gruner's original penciled notes contained a great deal of valuable information that was not in usable form. It was thought that it would be very desirable to type, organize, and file this original material, putting it in a more usable form and taking advantage of the fact that Dr. Gruner was still available to clarify any notations about which there might be questions. The office personnel at the Station undertook this work and completed it in three months.

A petrographer, Mr. Charles Beckman, was employed in January 1957 to make an intimate study of the rocks and minerals of the western Mesabi. To become familiar with his work, he first examined the many western Mesabi samples available in the University's Geology Department. Later, he spent three years collecting drill core samples from various places on the Mesabi and studying these petrographically. Mr. Beckman, who did his work in Pillsbury Hall, was supervised by Dr. G.M. Schwartz and was in close contact with Dr. J.W. Gruner, Dr. S.S. Goldich, and others of the Geology Department who were interested in the subject. In 1962, at the conclusion of the project, Mr. Beckman joined the geological staff of The Hanna Mining Company, who had become very interested in investigating the potential for treating nonmagnetic taconite.

A question of very practical interest was concerned with the quantity of potentially usable taconite available in the western Mesabi. During some early studies of the geology of the western Mesabi, Dr. Gruner had prepared a series of cross sections of the Range. These sections were given to Mr. A.J. Gleason, a retired mining engineer long connected with Pickands Mather and Company on the Mesabi Range, and Mr. Gleason classified the available material as best he could and completed a tonnage estimate of the cherty taconites of the Mesabi from Virginia to Sugar Lake, which is west of Grand Rapids. He divided the cherty taconite into three general types: magnetic taconite, nonmagnetic taconite, and mixed taconite. He estimated that there was more than 12 billion tons of nonmagnetic oxidized cherty taconite in this region.

In order to supplement the study that had been made by Mr. Gleason, it was desirable to make many laboratory tests on samples of taconite from known horizons and frequent points along the length of the Range. It was hoped that these tests would give quantitative information on the detailed concentration characteristics of the taconites. Wade sent letters to the mining companies operating on the western Mesabi to be assured of their whole-hearted cooperation, for it would be necessary to reply entirely on the companies for good samples. The project was intended primarily as an aid to the industry and he desired to develop his plan along lines that would be most acceptable. He also visited officials of the companies and discussed the project with them. The discussions were preliminary in nature, but he learned something of the information that was already available, what new information each company felt he should attempt to get, and obtained some suggestions on how he should proceed. The companies who eventually supplied samples were the U.S. Steel Corporation, The Cleveland-Cliffs Company, The M.A. Hanna Company, Great Northern Iron Ore Properties, Meriden Iron Company, W.S. Moore Company, and Pickands Mather & Company. Arrangements were also made with the Hibbing office of the Minnesota Department of Natural Resources (DNR) for the shipment of one or more crates of samples obtained by exploratory drilling. The DNR samples, weighing about one-third pound each, represented small footage increments for holes located at a number of points along the length of the Mesabi Range.

In the spring of 1957 the Cleveland-Cliffs Iron Company submitted the first samples for the project - taken from drill holes at four locations on the western end of the Mesabi Range. After typical specimens had been taken from the samples for petrographic examination, each sample was tested by a procedure that had been previously used by the Station staff to test a large number of western Mesabi materials. The same procedure was later used to test the samples submitted by other companies.

Each sample was first crushed to minus 6 mesh. Then a small portion of the minus 6-mesh material was ground through 150 mesh and magnetically separated. A 0.3 pound portion of the main sample was roasted to convert the nonmagnetic iron oxides to magnetite. The roasted material was then ground through 150 mesh and magnetically separated. The results of these tests provided a great deal of useful information. In general, they indicated that, wherever the iron formation had been oxidized, much of it was amenable to effective concentration.

When reported to the respective companies, the materials were classified according to their concentrating characteristics. The most desirable material, Class A, contained more than 20 percent magnetic iron and produced a concentrate assaying more than 62.50 percent iron. The Class B material contained more than 15 percent magnetic iron and the concentrate assayed more than 57.50 percent iron. This was marginal material which might be absorbed when mining higher grade ores but, if present in large amounts, would required special treatment. The Class C was material that did not fall into Class A or B but which contained more than 25 percent total iron. The Class D material included samples containing more than 15 percent total iron but which did not fall into the previous classes. Class E contained less than 15 percent total iron. A similar classfication was used for the roasted material except that the letters are followed by the subscript "1".

In August of 1957 samples from six drill holes submitted by the Oliver Iron Mining Division of the U.S. Steel Corporation were received. Test work on them was completed in September. Mr. Charles A. Beckman of the Station staff and Mr. David S. Gleason of the Great Northern Railway spent a very instructive week in the field with members of the geological staff of the Oliver Iron Mining Division.

In October of 1957 samples from six more drill holes submitted by the Oliver Iron Mining Division were received and tested. Again Mr. Beckman and Mr. Gleason visited the Mesabi Range several times. Mr. Beckman spent some time examining samples kept in storage by Meriden Iron Company and Great Northern Iron Ore Properties, and obtained samples from the drill holes representing locations for which there was need for additional information.

Early in 1958 samples from six holes were submitted by Pickands Mather and Company. Their drilling program, which had been carried on during the 40's, had been aimed toward the finding of magnetic taconite. Three of their sections between Keewatin and Hibbing encountered considerable mixed taconite which presented some interesting beneficiation problems. Pickands Mather & Company supplied the Station with the results of their magnetic roasting and concentration tests on samples from the southernmost hole in each of these three sections. The samples received were from holes further north in the same sections.

During January 1958 Mr. Beckman spent several days at the Oliver Research Laboratory in Duluth examining samples of their drilling on the western Mesabi. Samples from fifteen Oliver holes were received and were tested at the Station. In addition to the usual tests, the Station chemical laboratory completed determinations for a variety of elements on composite concentrate samples.

After a long search, in April 1958 Mr. James R. Gundersen was hired to head the Great Northern Railway Project. Mr. Gunderson was then 33 years of age, though he did not assume his duties until July. In 1949 he had received a bachelor of science degree from the University of Wisconsin where he majored in physics. In 1955 he had received his master's degree in geology from the University of California at Los Angeles, and in 1958 was completing his work at the University of Minnesota toward a doctor's degree. His graduate work gave him an excellent background of knowledge of the various minerals occurring in the Mesabi taconites.

During June 1958 Mr. Beckman and Mr. Gleason examined a number of drill hole samples of the M.A. Hanna Company and the test results were reported in August.

In September 1958 Mr. Rodney L. Bleifuss became a part-time employee on the Project. Mr. Bleifuss had received the degree of BS in Geological Engineering from Minnesota in 1951 and an MS degree in 1952. Since that time he had been in the employ of the U.S. Steel Corporation, where he obtained much valuable experience relating to the nature and utilization of low-grade iron ores. Mr. Bleifuss obtained a doctor's degree while at the Station and rose to the rank of Assistant Station Director before he returned to the U.S. Steel Corporation in 1973.

In September 1958 samples from additional drill holes were submitted by The M.A. Hanna Company, by Meriden Iron Company and by Great Northern Iron Ore Properties.

By late 1958 the samples tested had given a good indication of the concentration characteristics of the materials present in the Range west of Hibbing. A detailed time-consuming effort was made to correlate the metallurgical data with the mineralogical and petrographic information. Some of the geological information was assembled into a report that included maps that showed the location of the drill holes, the sample intervals, the hand-specimen locations, the thin-section locations, the stratigraphic distribution, and the zone of oxidation for the different members of the iron formation. Considerable preliminary information had been obtained and the results of many tests had been reported to mining companies on samples of nonmagnetic taconite that they had supplied. Although the work had created considerable interest in the possible utilization of Minnesota's nonmagnetic taconites, the project was a long way from completion. Since the Great Northern and the University felt that continued work might well be an important influence in stimulating commercial development, in May of 1959 they agreed to continue the project for an additional two years.

Dr. Gundersen and his assistants continued their detailed investigating of the various minerals occurring in the western Mesabi trying to obtain additional information as to their properties, and also studying their geologic occurrence.

During the summer of 1960 Dr. Gundersen and Mr. Bleifuss spent considerable time on the Mesabi. They collected about two dozen samples for testing at the Mines Experiment Station. Each sample weighed about 2000 pounds. During the ensuing winter and spring these samples were tested by roasting them in the Station's batch equipment followed by fine grinding and magnetic concentration in a continuous, 40-pound-per-hour flowsheet. Since this flowsheet used the same types of equipment that would be found in a commercial plant, rather reliable metallurgical information was obtained from relatively small original samples. Two carloads of material were also sent down to the Station and were tested in the station's pilot-plant roasting and grinding equipment.

All of the drill cores collected by Beckman, Gundersen, and Bleifuss were analyzed by magnetic tube tests and by reduction roasting followed by magnetic tube tests described previously. This procedure was followed because it seemed to offer a means of indicating roughly the percentage of iron by weight that was recoverable, the analysis of the product, and the units of iron recoverable from each sample. In other words, it provided a simple means of obtaining a great deal of useful metallurgical information. Later, Mr. Bleifuss made a petrographic study of samples from a number of holes, aided by a differential thermal analysis unit that had been purchased with project funds.

Although the information acquired and the conclusions reached during the project were believed to be accurate and meaningful, it was stressed that the scope of the investigation was necessarily very broad. It was neither practical nor desirable that particular prospective ore bodies be studied in detail.

The research work was conducted on two classes of samples. The first class was obtained through careful selection from the drill-core libraries of mine-operating and fee-owning companies. The selection was based on representative area and stratigraphic coverage and an avoidance of materials that showed strong resemblances to what is now classed as ore. These samples were cut from 106 drill-hole cores representing some 32,000 feet of drilling. The second class of samples, obtained after work had been completed on the first class, was a bulk type selected from places such as pit sides and bottoms.

The great bulk of the general information from the study, that is, from the testing and evaluation of many hundreds of individual samples, was distributed to the companies that furnished the samples. However, only the company that furnished a particular sample received the detailed information obtained from that sample. These results created considerable interest and may have had a part in influencing Hanna and Oliver to seriously study their own situations.

During the forties and fifties the U.S. Bureau of Mines was gradually moving from the University Campus to Fort Snelling on the south edge of Minneapolis. In about 1948 or 1949 a group of men (including Clem Burling) from the Bureau's staff on the Campus constructed a warehouse for drill cores on a portion of the Fort Snelling military reservation east of the Veterans Administration Hospital.
Then, in 1954 the Bureau's pilot-plant crew (Charles Prasky, Orvill Ahers, Will Swanson, John Zetterstrom, Al Humenansky, Erie Ely, and Carl Larson) moved to Fort Snelling to develop a sulfatization of manganese process. Carl E. Wood, Chief Metallurgical Division, Region V, and the remainder of the Bureau's staff stayed on the Campus until 1959, where they moved to a new building at Fort Snelling.

Immediately after the War, Mr. Needham, the Director of the Bureau's Region V; Matthew Sikich, head of the Statistical Group; and the statisticans maintained offices in the Buzza Building at 1006 West Lake Street, Minneapolis. In 1954 Mr. M.E. Volin succeeded Needham at Director of Region V. In 1959 Mr. Volin and the statistical group joined the other Bureau people at Fort Snelling.

CHAPTER 4 - THE SIXTIES AND SEVENTIES

Late in 1961, as the time for Henry Wade's retirement approached, the matter of selecting a successor was giving Eugene Pfleider, the Head of the School of Mines and Metallurgy, some concern. The position of Director of the Mines Experiment Station was not then an academic appointment. Changes in policy, however, had dictated that the new director be selected not only for his professional ability to direct research on the problems of the mineral resources of Minnesota (primarily iron ore) but also for his academic ability to teach at least one high-level course in mineral beneficiation or extractive metallurgy in the School of Mines and Metallurgy.

The position was not easy to fill. Having worked for the Mines Experiment Station for forty-six years, Mr. Wade had fully earned the confidence of the various administrative and research officials of the iron mining companies in Minnesota. In addition he had always maintained friendly relations with the members of the State Legislature, through whose action essential funds had been appropriated for the continued operation of the Experiment Station. All of this implied the maintenance of a nice balance between his obligations to applied and fundamental research, to the industry of the State, to the various political situations, and to the University. It would indeed be a difficult task to find a person who would fulfill all of the necessary qualifications and would simultaneously possess Mr. Wade's outstanding personal attributes.

Professor Pfleider and the faculty of the School of Mines and Metallurgy hoped to find a relatively young yet fairly experienced man with the right qualifications, possessing the necessary educational background, who could be trained for the position. The faculty interviewed a number of applicants before their selection settled on Dr. James E. Lawver, who succeeded Wade in April 1962. Dr. Lawver's background included several years of mining experience in South America and more than seventeen years in fundamental and applied mineral processing research. Before taking over the management of the Mines Experiment Station, he had been manager of mineral processing for International Minerals and Chemicals Corporation.

If the search committee had probed the entire world, they could not have found a man who was more unlike Henry Wade. They were direct opposites in every way. Wade was tall and slender; Lawver was of medium height with broad shoulders and strong arms. In fact, Lawver had been on the boxing and wrestling teams during his undergraduate days at the Colorado School of Mines, and had earned some of his expenses during college by working as a bouncer at one of the local night-spots. Wade was retiring, soft-spoken, and very courteous. Lawver was proud of his physical strength and exercised daily with some form of athletics, swimming, jogging, tennis, or weights. Wade was a slow and deliberate man who could work out any problem during a quiet period with pencil, paper, and simple mathematics. Lawver, on the other hand, was well versed in higher mathematics and brought to the Station the latest applications of controlled experiments and computer operations.

Perhaps it was well that there was such a change in directors. For nearly fifty years during the Davis-Wade era, there had been one way of doing things, an emphasis on pilot-plant operations, and, during recent years, on magnetic concentration and pelletizing. Though fundamental studies were being supported by Wade, he believed that the prime function of the Station was pilot-plant tests.

During the late fifties and early sixties, however, it was apparent that several factors were going to cause changes in the operations of the

Station. First: the nature of Minnesota's iron ore industry had changed. Natural ore shipments were decreasing, not only the direct shipping ores but also the gravity concentrates. Hence, no intermediate-grade ores had come to the Station for treatment for many years. The magnetic taconite process (concentration and agglomeration) was a commercial success, and the taconite companies were not sending such ores to the Station. Most of the recent service work had entailed magnetic roasting and concentration tests on low-grade Cuyuna ores, the results of which had not been encouraging. Second: the Dean of the Institute of Technology was advocating an emphasis on basic research at the Station. Third: early in 1962 a so-called Visiting Committee, appointed to review the programs of the School of Mines and Metallurgy, had recommended that the Station (which they considered to be a part of the School) not limit itself to industrial testing but should use graduate students in its research programs.

To implement these recommendations would require a whole new outlook. Ever since its establishment the Mines Experiment Station had been primarily an agency for applied research and service. Only a small part of its total effort had ever been devoted to fundamental research and to academic instruction. In the late 1930's the staff did initiate a one-quarter, undergraduate course entitled Iron Ore Beneficiation, which was still being taught when Lawver took over. However, this one course was the only participation that the staff had in academic affairs.

Early in his tenure, Lawver invited students to participate in the activities of the Station and offered several methods for their financial support. In 1963, for example, eleven students were employed on the Station payroll in one way or another. Graduate students received financial assistance by being employed as research fellows or research assistants. They were permitted to work up to twenty-five percent of their time, but their advising professors usually requested that the work week be held at fifty percent or less. As funds permitted, both graduate and undergraduate students were employed at the Station on an hourly basis simply by applying to the Station and clearing with the student employment office. They were not permitted to work more than twenty hours per week. At the same time, the old course in iron ore beneficiation was discontinued, and new courses in mineral dressing and operational research were offered.

In contrast to Wade, Lawver began to emphasize fundamental studies and to downgrade pilot-plant tests. In the research laboratories and in the pilot plant, he introduced new processes such as flotation, electrostatic separation, and high-intensity separation. To carry out these innovations, he began to hire new men. Two of them were Iwao Iwasaki to supervise the fundamental research and Ronald M. Hays to test the research in the pilot plant. A program of quarterly publications, liaison committee meetings with industrial leaders, and monthly symposiums was initiated.

In 1963 the staff of the Mines Experiment Station began working closely with the staff of the School of Mineral and Metallurgical Engineering (formerly the School of Mines and Metallurgy).[1] Professors S.R.B. Cooke, A.C. Dorenfeld, and G. Bitsianes even served part-time at the Station for a few months. It was the intention of Dr. Lawver to upgrade the staff of the Station so that they would be able to devote most of their time to fundamental work rather than to the applied program that was then underway. Dr. Lawver also hoped that by strengthening the bond between the two staffs he would be able to expand his graduate program and thus be able to conduct the basic studies that could not be justified if he used the funds from the special State appropriations.[2]

The influx of graduate students and new staff members put a severe strain on the facilities available at the Station. To obtain desk space for his additional people, Lawver revamped the existing offices. In 1963 partitions were erected dividing each of two large rooms on the ground floor into two smaller rooms. Upstairs, the former library was divided into four rooms: two small classrooms in the middle with an office at one end and a conference room at the other.

Since he intended to de-emphasize pilot-plant operations (in fact, there were rumors for a time that they would be eliminated), Lawver cast his eyes on the large amount of space in the pilot-plant bay. At first he considered converting the entire bay into small offices and laboratories and moving the pilot plant into the furnace room. That, however, would take a lot of money. For the present, he decided to build two graduate laboratories in the south end of the bay.

Ron Hays, however, had another idea. At that time the carpentry shop and the machine shop were in the basement, across the hall from the sampling room. Hays thought it would be advantageous to move the two shops upstairs into the proposed new rooms in the pilot plant.(After many years of step-climbing, the pilot-plant foreman, Clarence Nelson, and his assistants were inclined to agree with him). The vacated rooms in the basement could then be converted into graduate laboratories. Lawver obtained funds from the National Science Foundation and went ahead with Hays' plan. The new shops and laboratories were completed in early 1969. In 1973 two additional rooms were added over the shops, one to be used for reading and conference, the other for instruction.

The renovations did not by-pass the chemical laboratory. Soon after the mechanics had moved into the new shops and had vacated their former premises in the basement, the chemists moved into the old carpentry shop and for the next year and a half performed their tasks under most trying conditions while the chemical laboratory was being re-equipped with new cabinets, work benches, and plumbing. One might say: after forty-five years, it was about time. In December 1970 the chemists, Vernon Bye and Frank Lozar, moved into their new quarters. Their recent atomic absorption apparatus was housed in a small, former storage room between the old carpentry and machine shops.

Dr. Lawver also equipped a radioactive-tracer laboratory and a hydrometallurgy laboratory and hired new people to work in these laboratories. The pilot plant was also expanded by the addition of two autogenous grinding mills, several banks of flotation cells, and an electrodynamic separator. Much of the equipment for these laboratories was presented to the Station in the form of gifts or loans. The value of the gifts amounted to $29,300; the value of the equipment on loan amounted to $85,000.

By 1964 a number of basic research projects were under way. Dr. R.L. Bleifuss was studying the iron-manganese-silica system in reducing atmospheres by means of temperature x-ray diffraction. Mr. R.R. Beebe was investigating the flotation upgrading of magnetite concentrates. Dr. Iwao Iwasaki was trying various depressants for iron oxides in iron ore flotation and was developing a hydrometallurgical process for the recovery of manganese from Cuyuna ores.

The Station, working in cooperation with the University's Department of Bacteriology in 1967 developed a bacteria leaching system for the manganiferous iron ores and the iron sulfide ores of central Minnesota. Detailed mineralogical examinations and bench-scale beneficiation tests were made on samples of copper-nickel ore from northeastern Minnesota. Considerable effort was directed toward the use of Minnesota clays, and several metallurgical schemes to utilize the titaniferous magnetites of the State were investigated.

As in the past the research program of the Station was supported by funds received from the University and by special appropriations received from the Legislature. However, after five years under Lawver an ever increasing proportion of the Station's support came from out-of-state private companies and from the Federal government.

The major pilot-plant project of the sixties was the concentration of Mesabi semitaconites. As has been said, the Mesabi Range of Minnesota was then in a period of transition. Shipments of direct shipping ore and gravity concentrates, the so-called natural ores, had been decreasing and shipments of pellets from the new magnetic taconite plants had been increasing. Unfortunately, the expansion of pellet production had been insufficient to replace the losses in natural ore production, and total iron ore shipments had fallen considerably. Between 1958 and 1963 Mesabi shipments had averaged less than 46 million tons per year, whereas in the previous ten years annual shipments had frequently exceeded 60 million tons. In 1964, however, iron ore shipments totalled only 47,622,000 tons, of which 19,372,000 tons were pellets.

The shift in production from natural ores to pellets had been in response to the demands of the blast furnace operators for a high-grade ore with uniform chemical and physical properties. Mesabi mines unable to supply iron ore of the required grade and structure had shut down. Only the high level of activity in the steel industry had kept many others in operation.

As a consequence of the decreased production of iron ore, communities of the Mesabi Range had unemployment rates approximatley double that of the national average. The number of workers had slumped from nearly 18,000 in 1951 to 13,000 in 1964, about 6,000 in pellet production and 7,000 in natural ore mining.

In order to alleviate the distress on the Mesabi Range, in 1964 the Economic Development Administration (EDA) of the U.S. Department of Commerce sponsored a $90,000 project at the Mines Experiment Station to demonstrate a process for concentrating feebly-magnetic ores, or semitaconites, of the Mesabi Range. The process had been developed at the Station on a samll-scale, but with additional funds the process was to be demonstrated as workable by continuous runs in a pilot plant.

The project, which was under the direction of Ron Hays, involved the testing in the Station's pilot plant of a process that had been developed at the Station on a small scale, coupled with an economic evaluation of the process. Initially, the project aimed to develop a process for producing high-grade pellets from Mesabi "off-grade" gravity concentrates, gravity tailings, and semitaconites. During the course of the study, however, it became apparent that, to be practicable, the process would have to be capable of treating not only these comparatively coarse-grained and enriched materials, but also the unaltered oxidized taconites. This conclusion was based on the fact that such a process would not only greatly increase the total ore reserves available to the process, but would also eliminate the necessity for costly selective mining. Thus, the scope of the study was enlarged to include the testing of a carload of oxidized taconite to determine if such rock might also be used as a raw material. The portion of the investigation sponsored by the EDA was concluded in 1967, but funds from the Iron Range Resources and Rehabilitation Commission permitted the continuation of the study for another three years.

The process that evolved as a result of the study used wet, high-intensity, magnetic separation to produce an intermediate product whose grade was then further improved by froth flotation. When only two stages of magnetic separation were used, pellets containing 5 percent silica were produced at an iron recovery of only 77 percent. However, when three stages were used, the recovery was incresed to 85 percent.

After treating hundreds of tons of low-grade ore in the Station's pilot plants, Hays concluded that the process was applicable to the bulk of the feebly-magnetic materials found on the Mesabi Range. However, some of these raw materials contained considerable amounts of iron silicates. Since iron silicates have about the same magnetic properties as hematite and goethite, the iron silicates were recovered with the hematite and goethite in the high-intensity, magnetic concentrates. Similarly, other feebly magnetic materials contained goethite that was so fine-grained that physical separation by any means was impossible.[3]

The problems of the Cuyuna Range in Crow Wing County were not neglected by Dr. Lawver and his staff. After reaching a peak in 1953, Cuyuna iron ore shipments had decreased precipitously. Due to adverse grade, structure, and cost, most of the Cuyuna ores were no longer competitive with high-grade foreign ores and domestic pellets. The growth of open-hearth steel production had also decreased the need for manganiferous iron ores as blast furnace burdens. As a result of the decline in iron ore shipments, there was serious unemployment in Crow Wing County.

The economic distress on the Cuyuna Range led to numerous small and large-scale beneficiation tests on Cuyuna iron ores. Many different processes were investigated: magnetic roasting, froth, flotation, high-intensity magnetic separation, electrodynamic concentration, and hydrometallurgy. Several schemes were developed that would produce satisfactory grades and recoveries on selected samples. However, due to the difficulties of mining the steeply dipping beds, to the rather small blocks of ore available, and to the extremely fine-grained nature of most of the ores, none of the processes that were developed appeared economically attractive. The most likely process featured the employment of high-intensity wet magnetic separation followed by froth flotation and agglomeration.

Tests were also conducted on Cuyuna Range iron sulfides from Aitkin County. This material could be rather easily upgraded by flotation into a high-grade concentrate that could be used as source of sulfuric acid and as a source of iron. The economics, however, were unfavorable because the Cuyuna Range sulfuric acid would be unable to compete with acids from other sources.

In 1962 the R-N Corporation conducted a study on a manganiferous iron ore from the Cuyuna Range to see if it was amenable to their direct reduction process. It was hoped that an R-N plant could utilize Cuyuna ores that were either no longer salable as blast furnace feeds or could not be beneficiated economically to produce marketable concentrates. In addition to the production of an iron briquette, a high-manganese tailing was obtained.

Two years later the Economic Development Administration sponsored a study at the Station to determine the technical feasibility of producing high-grade manganese products from the tailing of a hypothetical Cuyuna Range R-N plant. The study, which was conducted by Dr. Iwao Iwasaki, Dr. R.L. Bleifuss, Mr. W.J. Carlson, and Mr. G.L. Tufford, concluded that it was possible to recover manganese as the metal, dioxide, or carbonate from the R-N tailing. A high recovery of both iron and manganese, however, would be difficult because the reducing conditions that favored the recovery of one adversely favored the recovery of the other. A high recovery of both metals could be effected if it were possible to remove most of the silica in the ore feed prior to the reduction step, but Cuyuna ores are in general so fine-grained that physical methods of beneficiation are impractical.[4]

During the late sixties the Mines Experiment Station, the School of Mineral and Metallurgical Engineering, and the Minnesota Geological Survey cooperated in a deep drilling project along the southern edge of the Mesabi Range. The drilling which was financed by a $100,000-grant from the Minnesota Iron Range Resources and Rehabilitation Commission, was done near Keewatin and Taconite in Itasca County and near Biwabik and Buhl in St. Louis County. Four holes, at 10-mile intervals were drilled to intersect the taconite formations at depths of 1,400 to 2,300 feet. The drill cores, whose mineralogical and chemical compositions were determined at the Station, indicated a vast extension of the known magnetic taconite reserves.[5]

In 1968-70 the Station continued its pilot-plant studies of the beneficiation of semitaconite and investigated in a small way the extraction of titanium minerals from the titaniferous magnetites of northeastern Minnesota. Further bench-scale work was carried out on the flotation concentration of Minnesota copper-nickel ore and on the bacterial leaching of Cuyuna manganiferous iron ore. Considerable attention was given to the electric and magnetic properties of minerals as part of an effort to design new kinds of magnetic separators for the State's taconite plants. An essentially all-dry magnetic taconite flowsheet was developed which promised to alleviate water pollution problems. Detailed studies were made on the role of bentonite in pelletizing and on the fundamental mechanisms involved in agglomeration and direct reduction.

On July 1, 1970 the Mines Experiment Station was retitled the Mineral Resources Research Center and was affiliated academically with the Civil and Mineral Engineering Department, a new administrative and academic structure formed by the integration of the School of Mineral and Metallurgical

Engineering and the Department of Civil Engineering. However, the Mineral Resources Research Center continued to operate as before under separate research budgets and to receive sponsorship from industry as well as from Federal agencies and special State appropriations.[6]

The 1973 Legislature did not appropriate any funds for the special support of the Mineral Resources Research Center. It was the first Legislature in over fifty years to withdraw its backing. The sixty-two percent decrease in funds provoked a major crisis at the Center. Sixteen members of the staff were laid off and the salaries of two senior scientists were reduced fifteen percent. It was not until 1979, when Legislators more supportive of the Center were elected, that special funds for the Center were restored. The academic functions of the Center were of course unaffected since they were supported by University funds. The Center continued to conduct research programs through increased dependence on industrial contracts. Lawver, through his nation-wide and world-wide acquaintanceship was able to obtain many substantial contracts. For the next two years the Center's pilot plant treated many tons of ore from Arizona, Alaska, Colombia, Chile, Angola, India, and elsewhere.

On July 31, 1975, Dr. Lawver resigned from the directorship to accept a position with his former employer, International Minerals and Chemicals Corporation. Mr. Ronald L. Wiegel, who had been Deputy Director since the previous October, became Acting Director. He served in that capacity for two years until he also joined International Minerals and Chemicals in Florida.

There was no State support for the Center in 1973-74, 1974-75, 1975-76, and 1976-1977. During 1977-78 and 1978-79 the Legislative Commission on Minnesota Resources granted temporary funds to the Center for the publication of the Mining Directory. State special support for the Center was re-established in July 1979 after a six-year lapse of funding.

Dr. Kenneth J. Reid became Director in September 1977. Under Dr. Reid, the work of the Center was divided into five divisions: mineral processing, process technology, environmental engineering, mining technology, and the underground space center. The work in the first three divisions was conducted at the Center, while mining technology and the underground space center were in the Mining and Metallurgy building.

During the late seventies there was an increased interest and awareness on the part of the Minnesota Legislature in both the technical and the environmental aspects of the potential development of the State's copper-nickel deposits. The particular concern for the potential environmental impact led to a study of the copper-nickel region by the Minnesota Environmental Quality Board. The study was commissioned in order to provide information for the use of the Legislature in the establishment of a policy which would govern the development of the copper-nickel deposits. For, although the Legislature had passed a tax law in 1967 to encourage the development of a copper-nickel industry, a number of serious environmental questions had risen in the ensuing years.

Though information for the study was provided by several agencies, one of the prime sources for mineral processing knowledge was the Mineral Resources Research Center. Recognizing the need for an independent evaluation of possible processing routes from a State viewpoint with particular concern for environmental factors, in 1977 the Legislative Commission on Minnesota Resources provided funds for the Center to carry out certain pilot-plant studies.

The objectives of the pilot-plant studies were to develop a realistic process for the concentration of the copper-nickel ore, to prepare mass balance data that could be used in the copper-nickel regional study, and to obtain detailed analyses of process streams with potential environmental impact. A significant factor in the studies would be the careful selection of those process options that would lead to a minimum overall environmental impact.

The pilot-plant studies carried out at the Center consisted of an investigation of a bulk flotation process (September 1977-March 1978) and an investigation of a differential flotation process (April 1978-August 1978). The ore for the studies, which amounted to nearly a thousand tons, was supplied by AMAX Exploration, Inc., from a copper-nickel lease that they held in northeastern Minnesota.

The process water was analyzed in detail for particulate content and chemical composition. The results showed a low chrysotile (an asbestos mineral) content. The normal copper, iron, and zinc contents of the Minneapolis tap water used for feed to the pilot plant were reduced by passage through the process.

A test bed made up of seventy tons of tailings produced during the tests was set up by the Department of Natural Resources near the AMAX mine to determine revegetation characteristics and the potential for heavy-metal ion release.

In September 1978, under Title III of the federal Surface Mining Control and Reclamation Act of 1977, twenty state mining and mineral resource institutes were marked for federal support. One of them was the University of Minnesota Mineral Resources Research Center. As part of that designation, the Center received a basic allotment of $110,000 a year for three years, a second grant for scholarships and fellowships of $160,000, and $100,000 in support of a research project. Since the allocation of the basic allotment was contingent upon matching State funds, the staff at the Center were very happy when the 1979 Minnesota Legislature re-established special support. With this new funding base the Center began to develop new, imaginative programs for research and training to meet a wide range of state, national, and professional needs.

In March 1979 Josef K. Tylko, vice president and director of research for Plasmatech, Inc., accepted a position at the Center as a part-time visiting professor, and supervised the establishment of a plasma technology laboratory at the Center.

In September 1980 Mr. Ronald C. Briggs came to the Center under an intergovernmental program, and began serving as Associate Director. Mr. Briggs salary was paid by the U.S. Bureau of Mines.

Early in 1981 the Minnesota Minerals Coordinating Committee, consisting of Matt Walton, Director of the Minnesota Geological Survey; Kenneth J. Reid, Director of the Mineral Resources Research Center, and Elwood F. Rafn, Director Division of Minerals, Minnesota Department of Natural Resources, met with the LCMR staff to discuss what the State needed in long-term mineral research.

CHAPTER 5 - SUMMARY AND OUTLOOK

Last year over ninety-nine percent of the iron ore that was shipped from Minnesota had been concentrated, and in the past 96 years nearly 1.5 billion tons of iron ore concentrate have been produced. The production of this concentrated ore has provided jobs for thousands of workers and hundreds of millions of dollars in taxes. The Mineral Resources Research Center can justifiably claim a good share of the credit for this production because most of the methods of concentration that are in use have been modified and improved by the Center, and some of the methods were originated there.

Although the early shipments of iron ore from Minnesota were all high-grade, direct-shipping ores, it was soon realized that there were large quantities of lower-grade ores and that these materials represented valuable resources which should be exploited. The Legislature recognized this siutation and appropriated funds for the establishment of the Mines Experiment Station (as the Center was first called) in 1911. Since that time, the Center has provided pilot-plant facilities where intermediate- and low-grade ores have been tested and new methods of treatment have been introduced and perfected by technically-trained personnel. During the life of the Center, a great variety of experiments have been conducted. These have included all sorts of concentration tests and hydrometallurgical and pyrometallurgical investigations. Jigging, a process which had been used to concentrate the ores of other metals, was first applied to iron ores at the Mineral Resources Research Center and was later successfully introduced on the Range where it is still in use in a few plants. The heavy density separation process was successfully applied to iron ores only after the original heavy medium, galena, was replaced by ferrosilicon in experiments at the Center. A magnetic taconite process, both the concentration and the pelletizing phases, was perfected at the Center and now has reached fruition in an annual production capacity of nearly 60 million tons. A small laboratory apparatus for determining the magnetic iron assay of samples of iron ore, commonly known as a magnetic tube concentrator, was invented by a member of the staff and is found in most ore dressing laboratories the world over. The alternating current coil which is used to demagnetize magnetite ore in many plants was also invented by the same staff member. Iron ore concentrate pellets were smelted, and very successfully, in a blast furnace for the first time at the Mineral Resources Research Center in 1948.

Since its establishment, fourteen special bulletins and seven information circulars have been published by the Mines Experiment Station in addition to fifty-seven editions of the annual Mining Directory. This directory contains descriptions of all mines in the state, together with the names of all operating companies, tonnages produced and remaining in their properties, and other statistical information. It is very widely used and the University is frequently complimented for publishing such a valuable bulletin.

These are but the highlights in a story of seventy years of steady contribution to the development of the mineral resources of the state-- a story of the introduction or improvement of processes which when put into use on the iron ranges has meant millions of dollars in payrolls and taxes. The mission of the Mineral Resources Research Center will never be completed for mining companies must treat ever more difficult ores and produce concentrates of ever greater quality to meet the standards of the steel mills. If these standards are not met, the steel mills will obtain their ore from other states or foreign countries.

During recent years the national concern has been focused on economic and energy problems. These problems have been risen rapidly over a relatively short period and during the process a major part of American society has lost sight of the vital fact that the only prime source of wealth and security is the earth itself from which minerals are extracted and on which agricultural produce is grown. The resolution of these economic and energy problems will require not only a major contribution by the mineral industry but also recognition and support from society at large.

During the past century Minnesota has supplied approximately two thirds of the domestic iron ore from which the steel to build the United States was extracted. The future of the United States will depend not only on the iron ore of Minnesota but also on many other strategic minerals which Minnesota has the potential to provide.

The discovery, extraction, and exploitation of Minnesota's mineral resources are subjects of vital concern. Research to facilitate the wise development of the State's mineral resources is an investment in the future, and the Mineral Resources Research Center is dedicated to the strengthening of the research and educational programs necessary to achieve these ends.

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6. Since 1909, ore estimates had been made by professors in the School of Mines. Sometime after 1911, this duty was reassumed by staff of the School of Mines.
7. President's Reports, 1912-13, page 81, University Archives.
8. For details of the burning of the School of Mines building, see excerpts from The Minnesota Daily for February 15, 18, and 19, 1913, in the Appendix, taken from the University of Minnesota Archives.
9. In 1918 several larger log washers were used in the Duluth experimental taconite plant. Eleven machines, 18 feet long and 6 feet wide were constructed at Babbitt, Minnesota, in 1921 by the Mesabi Iron Company for use in their iron ore concentrating plant, where they proved expensive to build and operate. Since they failed to reject coarse middling particles, magnetic log washers were not completely satisfactory. The Station built a medium-sized machine in 1925 for a short test in Spain. This was probably the last one manufactured.

Chapter 1 (Continued)

10. *Manganiferous Iron Ores of the Cuyuna District*, by Edmund Newton, Bulletin No. 5, Mines Experiment Station, University of Minnesota, 1918.

11. Royster, P.H., *Production of Ferromanganese in Blast Furnaces*, War Materials Investigations, No. 5, 1918-19, and Royster, P.H., *Production of Spiegeleisen in Blast* Furnaces, War Materials Investigations, No. 6, 1918-19.

12. *A New Machine for Concentrating Minnesota Wash Ores*, Bulletin No. 6, Mines Experiment Station, University of Minnesota, December 1919.

13. President's Reports, 1920-21, p. 148, University of Minnesota Archives.

14. President's Reports, 1911-14, University of Minnesota Archives.

Chapter 2

1. Memorandum, J.E. Julihn to M.L. Burton, 2 December 1919.

2. Letter, Appleby to Burton, 21 January 1920, Folder 203, President's Letters, 1911-45, University of Minnesota Archives.

3. Letter, Snyder to Burton, 27 January 1920, Folder 203, President's Letters, 1911-45, University of Minnesota Archives.

4. Letter, Appleby to Forsythe, Department of Architecture, 11 February 1920, Folder 203, President's Letters, 1911-45, University of Minnesota Archives.

5. Letter, Manning to Burton, 9 December 1919, Folder 203, President's Letters, 1911-45, University of Minnesota Archives.

6. Letter, Burton to Appleby, 9 March 1920, Folder 203, President's Letters, 1911-45, University of Minnesota Archives.

7. Letter, Snyder to Manning, 29 April 1920, Folder 203, President's Letters, University of Minnesota Archives.

8. Letter, Snyder to Manning, 25 May 1920, Folder 203, President's Letters, University of Minnesota Archives.

9. Letter, Forsythe to Coffman, 10 November 1920, Folder 203, President's Letters, University of Minnesota Archives.

Chapter 3

1. President's Reports, page 252, 1938-40, and page 84, 1940-42, University of Minnesota Archives.

2. President's Reports, page 84, 1940-42, University of Minnesota Archives.

3. President's Reports, page 125, 1942-44, University of Minnesota Archives.

4. A new set of job titles was introducted January 1, 1945 for technical people in the University Civil Service. Under these new titles, members of the Station staff who had formerly been called "metallurgists" were termed various ranks of "scientist".

5. President's Reports, page 98, 1944-46, University of Minnesota Archives.

6. President's Reports, page 84, 1946-48, University of Minnesota Archives.

7. Reports by H.H. Wade to A.J. Haley, Great Northern Railway Company, Files of the Mineral Resources Research Center, 1956-1962.

Chapter 4

1. On November 27, 1962 the name of the School of Mines and Metallurgy was changed to the School of Mineral and Metallurgical Engineering.
2. President's Reports, page 275, 1962-64, University of Minnesota Archives.

3. "Concentration of Nonmerchantable Iron-Bearing Materials from the Mesabi Range," Final Report for the Economic Development Administration, U.S. Department of Commerce, Mines Experiment Station, University of Minnesota, December 1967.

4. "Production of High-Grade Manganese Products from Cuyuna R-N Tailing," Final Report for the Economic Development Administration, U.S. Department of Commerce, Mines Experiment Station, University of Minnesota, November, 1966.

5. "Mesabi Deep Drilling Project," Progress Report No. 1 to Iron Range Resources and Rehabilitation Commission, State of Minnesota, University of Minnesota, Janaury 1968.

6. President's Reports, pages 189-90, 1968-70, University of Minnesota Archives.