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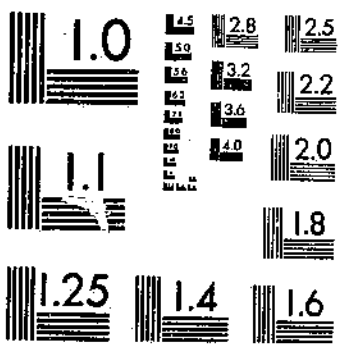

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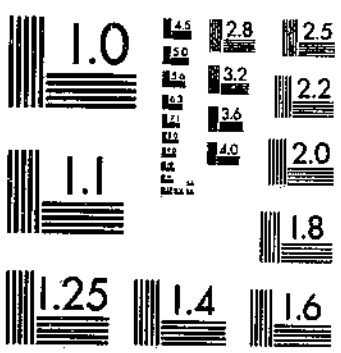

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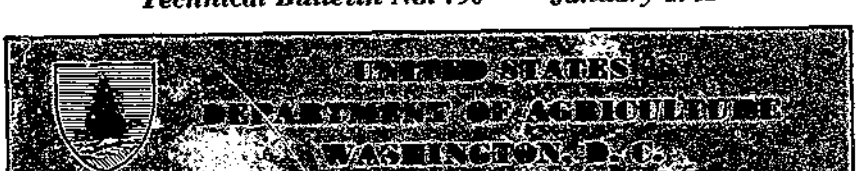

Wool Characteristics in Relation to Navajo Weaving[1]

By JAMES O. GRANDSTAFF [2]

Associate animal fiber technologist, Animal Husbandry Division, Bureau of Animal Industry

CONTENTS

INTRODUCTION

Hand weaving is an industry of considerable economic and social importance to the Navajo Indians (fig. 1). On and immediately adjacent to a reservation area of approximately 16 million acres in northeastern Arizona, northwestern New Mexico, and southern Utah, nearly 50,000 Navajos make their home.

Sheep raising has been the main occupation of these people for well over a century. After years of continued overgrazing, the land has become badly eroded and will not support a sheep industry of sufficient size to maintain the constantly growing Navajo population. The number of mature sheep and goats on the reservation has been reduced to about 550,000 head, but the total number of stock, including horses and cattle, is still considerably in excess of the carrying capacity of the range, according to estimates of the Soil Conservation Service, of the United States Department of Agriculture. With loss in numbers of sheep it is highly important that economic returns per animal be increased. Weaving is one of the principal means of

[1] Received for publication May 20, 1941. This study was conducted under authority of the Bankhead-Jones Act, in cooperation with the Bureau of Indian Affairs, United States Department of the Interior.

[2] The author acknowledges, with thanks, the cooperation of the following in furnishing specimens of old Navajo blankets and rugs for study: Laboratory of Anthropology, Santa Fe, N. Mex.; the Southwest Museum, Los Angeles, Calif.; the United States National Museum, Washington, D. C.; the Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, Mass.; the American Museum of Natural History, New York City, N. Y.; the Field Museum of Natural History, Chicago, Ill.; Mrs. Barbara Seymour, Mrs. H. C. Denny, and Barney Bertoneddi, Gallup, N. Mex.; Charles A. Amsden, Los Angeles, Calif.; T. H. Parkhurst, Santa Fe, N. Mex.; William H. Claflin, Jr., Belmont, Mass.; and E. O. Wooton, Washington, D. C.

Persons connected with the Southwestern Range and Sheep Breeding Laboratory, of the United States Departments of Interior and Agriculture, assisted with the study in the following respects: J. M. Cooper, director, made many helpful suggestions in the preparation of the manuscript; Walter L. Hodde, assistant scientific aide, assisted in the laboratory determinations, and Mrs. Lillian Brown, Navajo weaver, did all work connected with the weaving of experimental rugs.

accomplishing this objective. Approximately 750,000 pounds of wool, or about one-fourth of the total annual production on the reservation, are woven by the women into blankets and rugs.

The term "blanket" applies particularly to those specimens woven for use as wearing apparel prior to the change in tribal customs about

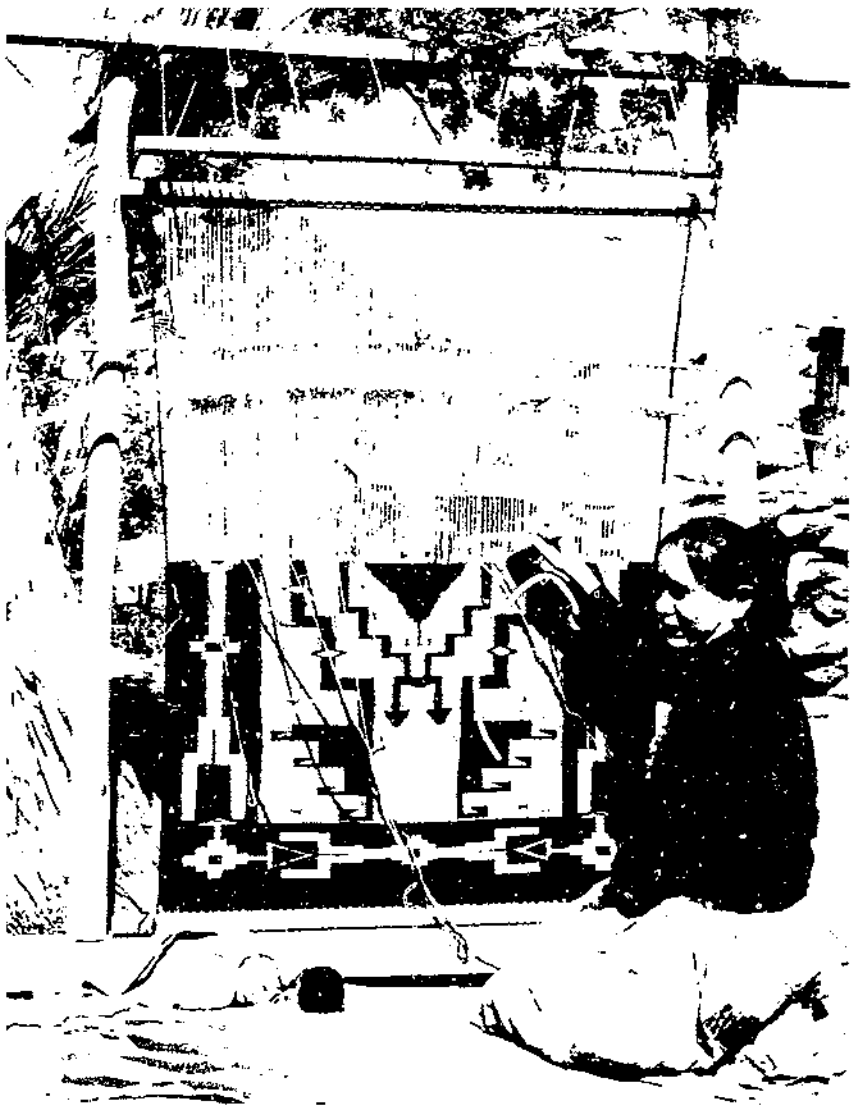

FIGURE 1.—Hand weaving of blankets and rugs is an important industry of the Navajo Indians.

1880, when manufactured blankets became available. They were worn around the shoulders and are therefore known as shoulder blankets. Those of superior quality were made from fine hand-spun yarns, so tightly woven as to be practically waterproof. Rugs are

intended for floor coverings and are generally woven from heavier yarn than that used in the old shoulder blankets.

At present both blankets and rugs are used extensively in the Southwest for floor coverings and other interior decorations, as well as for saddle blankets and miscellaneous outdoor purposes. The bold geometric designs and mixed bright colors characteristic of Navajo weaving are best adapted to the southwestern type of homes. Large numbers of blankets and rugs also find their way to other parts of the United States, because of their value as a unique hand-woven textile.

Raw wool is subject to wider annual price fluctuations than Navajo blankets and rugs, but for the last few years incomes from these two sources have been approximately the same. Surveys covering most of the large trading posts on and adjacent to the reservation indicate that Navajo families have received about $385,000 annually from blankets and rugs, not including those bartered or retained for personal use. The actual cash income from weaving represented only about one-fourth of the total livestock income, but it was of vital importance to the Navajo people for it provided employment and income when other sources were inadequate. In periods of economic depression or in years of severe drought, the almost universal knowledge of weaving among Navajo women comes to their aid. It is often the principal means of subsistence for large numbers of families, particularly during the winter months.

Weaving is more than a source of income: it is a handicraft that has played a dominant part in the cultural development of these people for at least a century and a half. In design, coloration, and weaving of blankets and rugs, Navajo weavers have found abundant opportunities for creative skill and artistic expression.

The time of origin of the craft is somewhat obscure, but translations of the early Spanish documents have revealed that weaving was an established enterprise among the Navajos by the early part of the eighteenth century. Hill (*7*) [3] states that "The woven wool blanket was apparently well known by 1706, the earliest reported date for Navajo weaving." About 100 years later eastern explorers began to come into the Southwest, and frequent mention was made of the fine blankets made by this tribe. Gregg (*4*) called these blankets "Serape Navajo" and spoke of their waterproof character. Since 1900, several extensive volumes have been written on the subject of Navajo weaving. James (*8*) and others traced the development of the handicraft, with particular emphasis on its aesthetic and artistic value. Amsden (*1*) made a comprehensive study of the technique and history of Navajo weaving in relation to its social and economic importance. He recognized that the quality of Navajo rugs was related to the characteristics of the wool used. Furthermore, he expressed fear for the permanence of the craft unless steps were taken to insure a supply of suitable weaving wool.

The quality of Navajo rugs, as measured by their uniformity and smoothness of texture, has steadily declined during the last two decades. A large proportion of the rugs woven on the reservation have been lumpy and uneven in texture, as illustrated in figure 2. Paralleling the decline in rug quality, there has been a pronounced change in the physical characteristics of most of the wool produced on the reservation, thereby affecting its adaptability for weaving purposes.

[3] Italic numbers in parentheses refer to Literature Cited, p. 36.

This change has been brought about by the cross-breeding of the native Navajo sheep with rams of other domestic breeds, for the purpose of improving their wool and mutton qualities for the commercial market. In 1939 not more than 5 percent of the wool produced on the reservation was of the Navajo type.

The Navajo sheep (fig. 3) produce a small fleece of light-shrinking wool, composed of an undercoat of short, fine, true wool fibers and

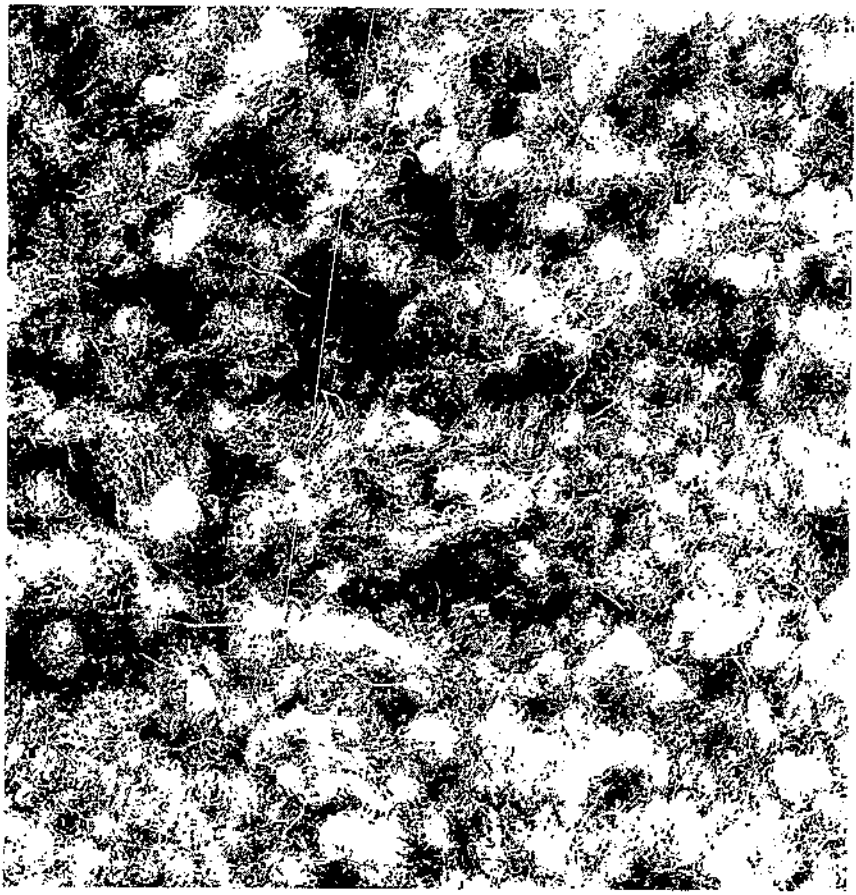

FIGURE 2.—Lumpy texture of inferior Navajo rug woven on the reservation from wool of grade Rambouillet sheep. × 2. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)

an outercoat of long, coarse, hairlike fibers as shown in figure 4. In common with unimproved wools, the fleeces also contain varying quantities of kemp and other medullated fibers. Kemp is a short, coarse, opaque, nonelastic fiber. Wool of this type is well adapted for Navajo weaving, since it requires little washing and can be hand-carded and spun with ease.

Extensive use of Rambouillet rams since 1920 has resulted in a fine, short-stapled, heavy-shrinking wool with a well-defined crimp. Each of these factors has contributed to a decrease in suitability of the wool

for hand weaving, thereby resulting in the production of rugs of inferior quality. From her experience in hand carding, spinning, and weaving under the supervision of Navajo women, Reichard (*11*) concluded that the low production of the Navajo sheep was of minor importance to the weaver as compared with the desirable character of the staple and its relative freedom from grease. For hand carding and spinning, the extreme crimpiness of the Rambouillet wool is a severe handicap, as the Navajo weavers must achieve with primitive implements and hand power that which commercial manufacturers attain with power machinery.

Indian traders, Government officials, and others concerned with the welfare of the Navajo people are now aware of the danger facing the

FIGURE 3.—Ewes in the experimental flock of Navajo sheep at the Southwestern Range and Sheep Breeding Laboratory, Fort Wingate, N. Mex.

handicraft, and efforts are being made to remedy the situation. Many of the traders have been active for years in encouraging their weavers to improve their workmanship and to use pleasing rug designs in harmonious colors. Instruction in weaving is now given in most of the Navajo schools, and here, as well as in certain localities on the reservation, the trend is toward the use of simple designs. Soft colors produced from native vegetal dyes or combinations of black, brown, gray, and white wool, either natural or dyed, are preferred. Other colors are not objectionable when used in simple, harmonious combinations. In the schools wool of the native type is provided, and Navajo girls are taught the steps necessary in the preparation of this wool for the weaving of a smooth, high-quality rug.

Recognition by the Government of the importance of rug weaving to the Navajos was the main factor that led to the application of

scientific methods in solving the sheep and wool problems of these people. Convinced of the need of research on the subject, the Office of Indian Affairs, United States Department of the Interior, requested the services of the United States Department of Agriculture. Accordingly, B. Youngblood of the latter Department made an intensive study of the needs of the Navajo Indians. He found [4] that sheep and wool were their major economic and social assets. He stressed the need for the preservation of the Navajo sheep because of their importance to the weaving handicraft. Improvements in the sheep

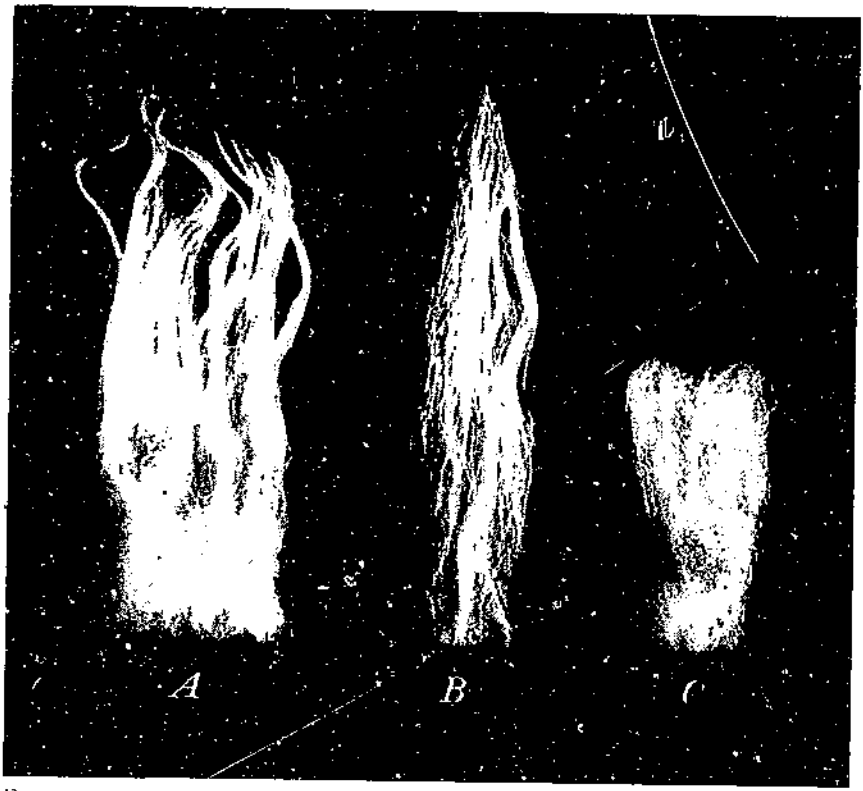

FIGURE 4.—A lock of Navajo wool (*A*) separated to show long, coarse, outercoat fibers (*B*) and short undercoat fibers (*C*).

were deemed essential to the economic security of the Navajo people because of low production of wool and mutton. Furthermore, it was felt that improvements in Navajo wool from the standpoint of rug making would result in better wools for carpet manufacture. Such wools would have a more favorable place in competition with cheap, foreign-grown wools.

To develop a type of sheep adapted to the conditions prevailing on the Navajo reservation and better suited to the economic needs of the Navajo people, the Southwestern Range and Sheep Breeding Laboratory, a cooperative research agency, was established by the United

[4] YOUNGBLOOD, B., WALKER, A. L., and BROSTROM, WM. NAVAJO TRADING. 128 pp., illus. 1935. [Mimeographed.]

States Departments of Interior and Agriculture at Fort Wingate, N. Mex., in 1935. Fundamental to the progress of this project was the need for data on the physical properties of wool best suited for Navajo weaving.

PURPOSE OF STUDY

Many of the old Navajo blankets and rugs now owned by museums and private collectors represent a quality of product that has seldom been equalled in recent years. The excellence of these old specimens attests not only to the weaver's skill, but also is substantial proof that the wool used in them possessed certain physical characteristics that are highly desirable for the weaving handicraft. Such characteristics involve suitable length, fineness, diameter distribution, crimp, density, and shrinkage. The purpose of this study, which was conducted at the Southwestern Range and Sheep Breeding Laboratory in 1937–39, was to determine by scientific methods the physical characters of Navajo wool that make it particularly adapted to the simple methods of carding, spinning, and weaving used by Navajo women. The various phases of the study were (1) to determine the influence of fineness, fiber-diameter dispersion, and variations in fiber-diameter distribution, length, shrinkage, crimp, and frequency of kemp and other medullated fibers on the quality and texture of rugs woven from wool grown by experimental sheep maintained at the laboratory; (2) to measure, insofar as possible, those wool characteristics that contributed to the relative excellence of the old blankets and rugs; and (3) to compare the physical properties of the wool used in these old specimens with those of wool from the experimental sheep.

MATERIALS AND METHODS

Rugs Woven From Wool of Experimental Sheep

Experimental hand weaving was done with selected lots of wool produced by the breeding flock of Navajo sheep maintained at the laboratory. As a basis for this flock, 800 ewes and rams were purchased in 1935 and 1936 from Indians living in remote parts of the Navajo reservation, where the influence of the white man had been felt the least. These animals were descendants of the native sheep.

SELECTING AND ANALYZING SAMPLES OF WOOL

Since average fineness, proportion and length of undercoat and outercoat fibers, and quantity of kemp and other medullated fibers varied to a considerable degree in different parts of the fleece, it was essential to exercise the utmost control by careful selection and sorting. First, all tags and off-sorts, as well as the belly and leg wool, were removed from each fleece. The thigh wool was next removed because it generally contained too high a proportion of coarse fibers.

From various parts of the remaining portion of the fleece 5 small samples, each weighing about 20 gm., were taken for fiber-diameter measurements. These samples were thoroughly mixed by hand, then carded and spun into a loose yarn from which 5 pieces were taken, at random, for cross-sectional study of the fibers. One hundred fibers from each piece were measured, making a total of 500 for the composite sample, representing a lot of 1.5 to 2 pounds of wool. Fiber-

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diameter measurements were made from the projected image of the cross sections by the method developed by Grandstaff and Hodde (*3*). The average of the major and minor axis of each fiber was obtained in microns by means of a transparent celluloid bidiameter scale. The quantities of kemp and other medullated fibers were also determined from the cross sections. In a magnified image of the fiber cross sections, the medullae appeared as dark areas and were easily distinguished from the surrounding cortex. Classification of the medullae was made on the basis of size. A medulla occupying not more than 25 percent of the cross-sectional area of the fiber was classified as small, one ranging from 26 to 50 percent as medium, and from 51 to 65 percent as large. Those fibers containing more than 65 percent of medullae were classified as kemp. The kemp fibers were generally much larger than the other types and usually ribbon or bean shaped in cross section.

Another composite sample, consisting of five samples from various parts of the fleece and weighing about 160 mg. each, was used for the length analysis. The Suter wool stapler, commonly used for fiber-length analysis of wool top, provided an efficient and satisfactory means for separating the long, hair fibers of the outercoat from the short, fine fibers of the undercoat. After separation, each of the two types of fibers was measured in centimeters, weighed on a microbalance, and the percentage of the total weight calculated.

For the determination of shrinkage, a 30-gm. sample was taken from the left side and one from the right side of each fleece. These samples were oven-conditioned to a constant weight before and after scouring. The term "shrinkage" as herein used means the difference in percentage between the dry weights of the unscoured and clean wool. The loss in weight represents the yolk, suint, sand, and other foreign material removed in the scouring process.

For measurements of crimp, samples of 200 fibers each from 1 lot of typical Navajo wool and 1 of grade Rambouillet wool were used. The length of each fiber was measured with the aid of 2 pairs of tweezers having fine serrated points and also with a millimeter rule mounted on a black background. The fiber, held at the base and tip ends, was measured in a natural crimped condition. It was then measured in a straightened condition by holding the fiber under sufficient tension to remove the crimp. The difference in percentage between the length of the straightened and crimped fiber was used as a measure of crimp.

After the laboratory analyses, the various lots of wool were woven into small rugs by a Navajo weaver employed at the laboratory.

Old Navajo Blankets and Rugs

A total of 162 old Navajo blankets and rugs were used for study. They were selected from 6 of the largest museum collections in the United States and from 7 of private ownership. These blankets and rugs were woven over a period of more than a century—from about 1800 to 1915—and therefore antedate the recent period of decline in quality associated with the many changes in characteristics of the wool.

Some major differences were apparent in the character and quality of the specimens woven during the early, middle, and latter parts of

the last century. Previous writers have attributed these differences to the influence of external factors associated with the changing environment of the handicraft. It seemed probable that differences in certain characteristics of the wool used for weaving might also have contributed to variations in the excellence of the hand-woven product. As a means of obtaining definite information on this point, all blankets and rugs were classified into four chronological periods. The various factors considered in making this classification were: Design, dyes and colors, quality of workmanship, intended use of the product, various

FIGURE 5.—Fragments of Navajo blankets originating in the early part of the nineteenth century, woven in stripes on a white background. (Courtesy of Peabody Museum, Harvard University, Cambridge, Mass.)

types of manufactured yarns used for either the warp or weft, and comparison with specimens of known age.

The first period included one entire blanket and seven odd fragments that have survived from the early part of the nineteenth century (fig. 5). These specimens were recovered years ago, mostly from Navajo burials, as the result of archaeological research in the caves and prehistoric ruins in Canyon de Chelly and Canyon del Muerto, Ariz. They were woven in horizontal stripes of natural-colored or native-dyed yarns on a white background. The yarns were mostly medium coarse. In some specimens the yarns were loosely spun and woven, whereas others showed evidence of better workmanship in the form of more even yarns, tightly battened down.

Following these early examples of weaving, others are apparently unknown until about the middle of the century. The second period,

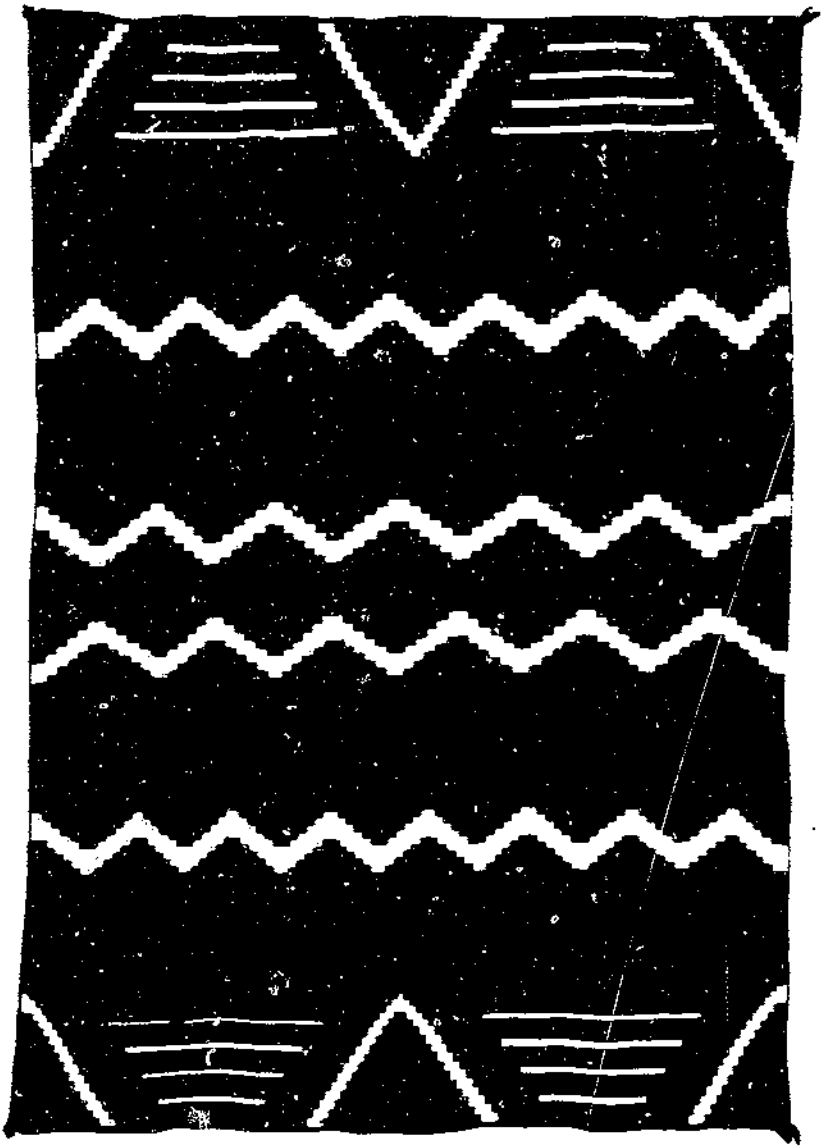
dating from 1850 to the early seventies, contained 41 specimens. Many of them were collected by Army officers, private connoisseurs, and Navajo traders, who later donated, sold, or loaned them to the museums. They were predominately of two distinct and select types of blankets, both of which were used as articles of wear among the more important Navajo tribesmen. They were also a principal item of barter to the Indians of surrounding tribes and well-to-do Mexicans of the Rio Grande valley. In fineness and uniformity of yarns, tightness, smoothness, and texture of weaving, as well as excellence of design, these blankets surpass all other Navajo types. They may well be termed the masterpieces of the Navajo weavers' art.

In the type referred to by Mera (*10*) as the Classic blanket (pl. 1), the design consisted in various arrangements of two fundamental forms—simple stripes and stepped zigzags or terraces. The stripes, when used, generally formed a part of the background. Another distinguishing feature of this type of blanket was the red bayeta yarn, which was raveled from a coarse woolen cloth manufactured in England and imported into this country by way of Spain and Mexico. Navajo weavers respun the bayeta into a two-, three-, or four-ply yarn and used it extensively because of its bright color and fine texture. Commercial yarns of other colors, particularly green, were sometimes used. The hand-spun yarns, made from native wool, were generally white or dyed indigo blue. Although very fine and smooth, they were not so tightly twisted as those of commercial origin.

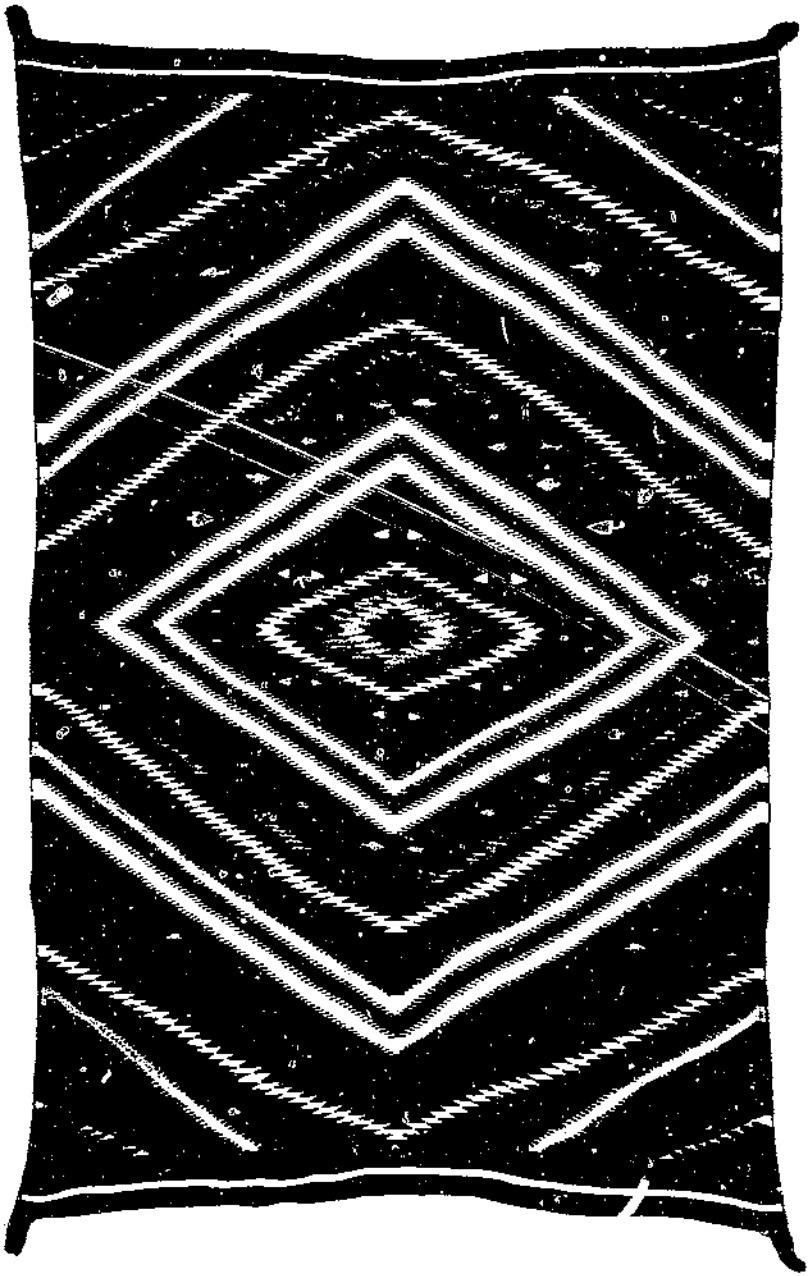
The other predominating type represented in the second period was the Chief blanket (*9*). The design consisted of alternating broad bands of natural brown or black and white. In some instances a narrow stripe of indigo blue was inserted next to the marginal bands. Specimens associated with the latter part of the period included an insert of oblong blocks at the center and ends of the median and lateral bands. The rectangular figures were generally woven from raveled yarn similar to that used in the Classic blankets.

Diamonds in a great range of sizes and a wide variety of combinations were a principal element of design in the rugs of the third period (pl. 2). This period covered approximately the two decades following the return of the Navajos from Fort Sumner, N. Mex., to their former habitat and present reservation. The revolutionary changes of an economic and social nature that occurred during this time are believed to be largely responsible for the greater differences, in character and quality, of the 85 blankets and rugs of the third period, than of those woven preceding this time. It was a period of transition in Navajo weaving, which witnessed the gradual transformation of the blanket into a rug for the white man's use. To meet this demand, the traders introduced cheap cotton twine to replace the native wool warp of earlier times. Brightly colored three-ply Saxony and four-ply Germantown yarns were a quick substitute for the bayeta; and aniline dyes, purchased in a form ready to use, displaced the native colorants of infinitely finer tone and greater fastness. These materials were stepping stones in the phenomenal growth of the weaving industry. Yet their detrimental influence on the handicraft caused all except aniline dyes to be eliminated from general use after a few years of popularity.

The fourth period covered about 25 years, extending from 1890 to 1915. A total of 28 rugs woven in this period were studied. One of



A choice old Navajo blanket of Classic design, size 51 by 72 inches, woven in the second period, 1850 to 1870. This blanket represents near perfection in Navajo weaving. The red is ravelled bayeta used in two strands; the white and blue yarns are hand-spun from Navajo wool. Yarn count, 13 warp and 71 weft per inch. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)



A Navajo rug of superior quality, size 51 by 83 inches, woven in the third period, 1870 to 1890. The red background is made of aniline-dyed, hand-spun yarns of Navajo wool. Yarn count, 8 warp and 38 weft per inch. The colored yarns used in the designs are commercial four-ply Germantown in two strands. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)

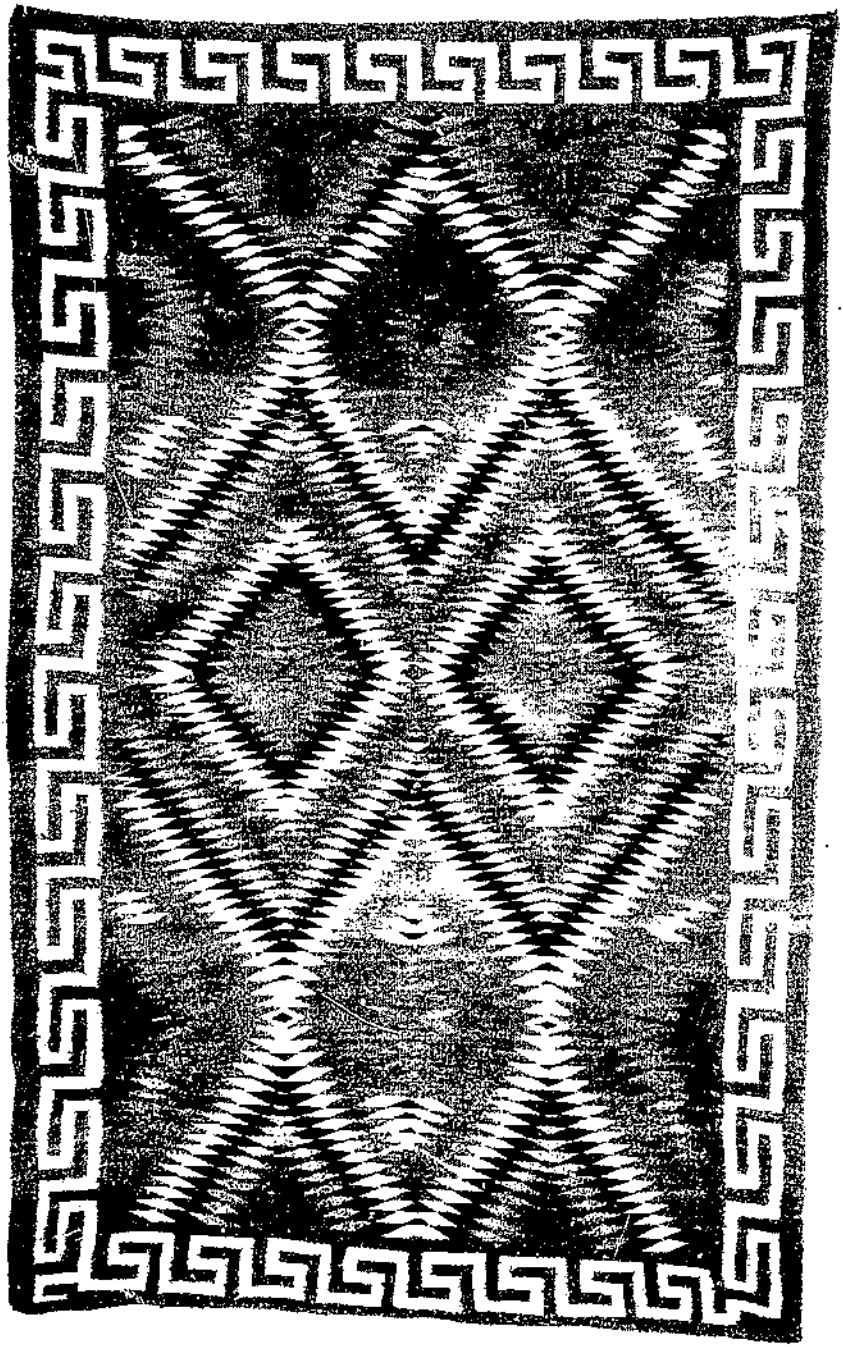


FIGURE 6.—A bordered rug of the fourth period, 1890 to 1915, woven from Navajo wool. Yarn count, 5 warp and 20 weft per inch. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)

their principal distinguishing features was the use of a border around a central design (fig. 6). From 1890 to 1920 the border was popular with Navajo weavers, but of late years it has given way to the revival of earlier styles. At the time of this study, many of the rugs in this group were still in actual use in private homes.

OBTAINING AND ANALYZING YARN SAMPLES

Small samples of weft yarns approximately 1½ inches in length were taken from each blanket or rug for laboratory determination of the cross-sectional characteristics of the fibers. The locations from which the yarns were taken depended largely on the condition of the fabric. The samples were taken adjacent to a broken place in the specimen whenever possible. If the blankets or rugs were in perfect condition, as many of them were, it was then necessary to examine the surface carefully to locate the free end of a yarn that could be teased out for a short distance and cut off. In most instances the samples were taken from several different locations on the specimen. The warp could not be sampled, except in a few badly worn specimens, without doing serious damage. Each set of yarn samples was identified with either the owner's name or an assigned number, together with a brief description of the specimen. When possible, a photograph was also made to insure positive identification of the source of the sample.

The yarn samples were cross-sectioned by use of the rapid techniques described by Hardy (*5*, *6*). The device for making thick sections was used for the white yarns, and the device for thin sections was used for the dyed or natural brown, black, and gray yarns. The thin sections were mounted on microscope slides in Canada balsam. Sections of not more than 10μ in thickness furnished the best microscopic image. Considerable difficulty was experienced in the preparation of the thin sections, owing to the fact that the fibers had become extremely hard and brittle with age.

The fiber cross sections were measured and classified for medullation as previously described for the experimental rug samples.

EXPERIMENTAL RESULTS

Rugs Woven from Wool of Experimental Sheep

In the first of three experiments, the most desirable fineness of Navajo wool for hand carding, spinning, and weaving was determined. For this test five lots of wool, each representing a different degree of fineness, were selected. Four of the lots consisted of Navajo wool and one (lot 5) of a grade Rambouillet wool. The mean fiber diameters and lengths of staple of the various lots are shown in tables 1 and 2. Each lot of wool was of medium variability in diameter for the fineness that it represented. Table 3 shows a comparison of the wools on the basis of shrinkage. Samples of the wool and resulting hand-spun yarns are illustrated in figures 7 and 8, respectively.

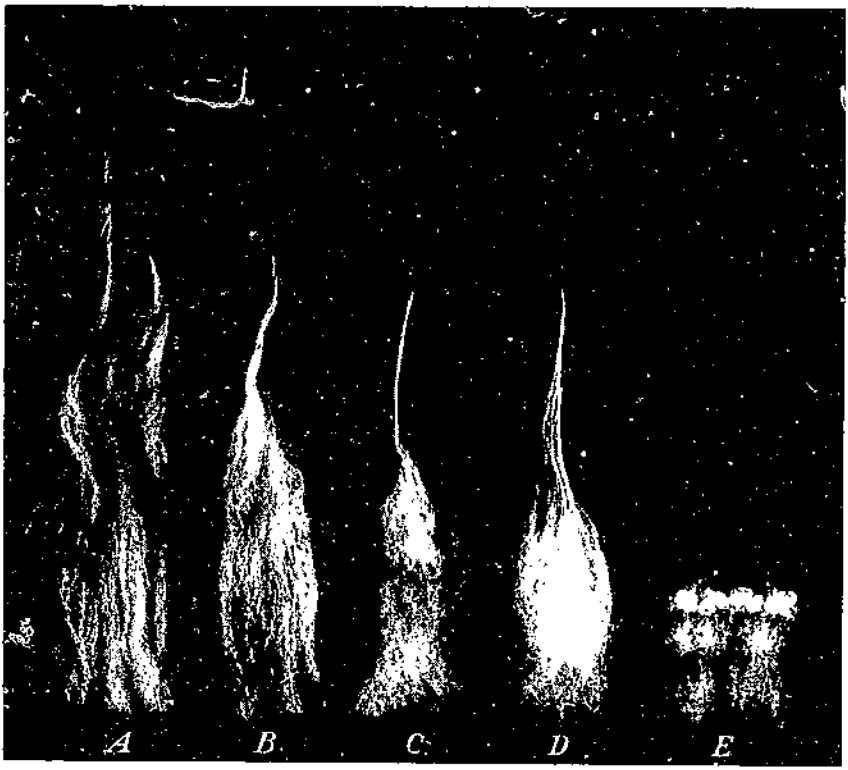


FIGURE 7. Samples of wool showing variations in length and proportion of outercoat fibers: *A* to *D*, Navajo wool; *E*, grade Rambouillet wool, similar to that produced on most parts of the Navajo reservation.

TABLE 1. *Mean fiber diameters, standard deviations, and percentages of kemp and other unmedullated fibers in five lots of Navajo wool and one lot (No. 5) of grade Rambouillet wool experimental*

Lot No.	Locality	Number of fibers measured	Fiber diameter						Medullated fibers				
			Mean	Standard deviation	Percent less than 20 μ	Percent less than 25 μ	Percent less than 30 μ	Percent less than 35 μ	Mean diameter	Standard deviation	Kemp	Other unmedullated fibers	Total
			Microns	Microns	Percent	Percent	Percent	Percent	Microns	Microns	Percent	Percent	Percent
1	Ganado, Ariz.	1,000	21.4	4.5	53.8	81.6	93.8	97.4	27.8	3.2	0.2	2.4	2.6
2	Keams Canyon, Ariz.	1,000	22.2	4.7	50.8	78.4	91.7	96.5	28.0	3.3	0.6	2.9	3.5
3	Shiprock, N. Mex.	1,000	20.5	4.0	61.8	86.4	95.4	98.3	26.8	3.1	0.1	1.4	1.5
4	Tuba City, Ariz.	1,000	23.1	4.7	43.0	72.8	89.6	95.8	28.3	3.3	0.8	3.3	4.1
5	Rambouillet	1,000	23.1	5.1	42.4	69.3	87.1	94.2	28.0	3.3	0.2	1.2	1.4

[Average for the fourth lot not computed]

[Median diameter, 22.9 microns; standard deviation, 4.7 microns; percentage of fibers less than 20 microns, 45.0; less than 25 microns, 70.6; less than 30 microns, 88.2; less than 35 microns, 96.0]

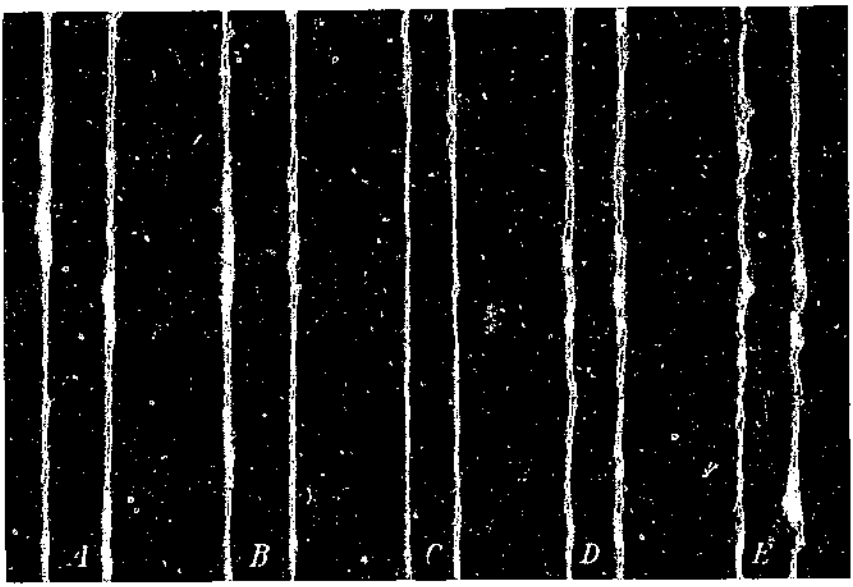


FIGURE 8.—Hand-spun yarns made from wool illustrated in figure 7, lettered in the same order. Note uniformity and smoothness of middle set of yarns, which were spun from wool of medium fineness, containing 13 percent of fibers more than 40μ in diameter. Note also irregularity of yarns on extreme right, made from grade Rambouillet wool.

TABLE 2.—*Length and proportion of outercoat and undercoat fibers in four lots of Navajo wool and one lot (No. 5) of grade Rambouillet wool (experiment 1)*

Lot No.	Outercoat fibers		Undercoat fibers	
	Length	Proportion by weight	Length	Proportion by weight
	Centimeters	*Percent*	*Centimeters*	*Percent*
1	20.7	37.4	17.1	62.6
2	17.8	37.6	8.2	62.4
3	17.8	19.7	10.8	80.3
4	18.1	22.9	10.2	77.1
5	0	0	7.7	100.0

TABLE 3. *Weights and shrinkage of four lots of Navajo wool and one lot (No. 5) of grade Rambouillet wool*

Lot No.	Experiment 1				Lot No.	Experiment 2		
	Weight of wool		Shrinkage			Weight of wool		Shrinkage
	Unscoured	Scoured				Unscoured	Scoured	
	Grams	*Grams*	*Percent*			*Grams*	*Grams*	*Percent*
1	26.1	18.1	29.5	1		14.9	20.0	35.6
2	19.9	10.3	18.1	2		23.9	15.0	31.1
3	12.5	24.8	11.6	3		26.6	13.8	48.1
4	22.9	13.8	39.7	1		29.7	18.1	39.2
5	26.9	6.5	68.8	5		39.9	13.7	65.7

Lot 1 represented the very coarsest of the Navajo wool and was equal in mean diameter to U. S. grade 44's. The diameters of the fibers, when arranged in sequence, formed a distinctly bimodal distribution, with 30.8 percent of the fibers more than 40μ in diameter. By actual weight the outercoat represented 37.4 percent of the sample. The wool was difficult to card by hand because of the extreme length of the outercoat. Moreover, the proportion of coarse, straight fibers was excessive in this wool, resulting in a loosely spun yarn, coarse and fuzzy in appearance. The finished rug had a heavy nap and was coarse in appearance and texture.

Lot 2 was similar in average fineness to grade 48's. Although lots 1 and 2 had about 37 percent by weight of outercoat fibers, the latter contained about 10 percent less extremely coarse fibers. The improvement in texture of the rug made from wool of lot 2 over that made from lot 1 indicated that extreme coarseness of outercoat was an important factor contributing to undesirable rug texture.

Lots 3 and 4, of average fineness (equal in mean diameter to grades 50's and 56's), produced smoother yarns with a high degree of uniformity in diameter. The rugs woven from these yarns were superior to those obtained from either the coarser or finer wool. The greater predominance of undercoat fibers in the wool of lot 4 than in lots 1 and 2 increased the softness of the rug, but this effect was partially counteracted by the greater frequency of coarse kemp fibers.

The wool in lot 5, which was the finest of the wools studied, was similar to that used for weaving in many parts of the reservation, where the sheep show effects of the introduction of Rambouillet blood. This wool was the most difficult to card and spin, as evidenced by the irregularity in diameter of the yarns and the lumpy texture of the finished rug (fig. 8, *E*). The difficulty experienced in this instance can be traced to the pronounced crimp, characteristic of fine wool. In the lot of grade Rambouillet wool studied, an average of 28.2 percent of fiber length was due to crimp. On the other hand, in a lot of Navajo wool similar to that of lot 3, the undercoat fibers averaged 15.3 percent of crimp and the outercoat fibers 9.4 percent. Variations in the amount of crimp in Navajo fleeces were not considered sufficient to influence the suitability of the wool for hand weaving, whereas the difference between the grade Rambouillet and Navajo wools was considered important. Furthermore, the crimps in the Rambouillet wool were close and well defined in a high proportion of the fibers, whereas in the Navajo wool they varied greatly in form. In the finest fibers the crimps were most uniform but increased greatly in length and irregularity with the size of the fibers. The comparatively high shrinkage of the Rambouillet wool was an undesirable factor because of the difficulty of scouring such wool by hand methods. An excessive quantity of grease in wool is a handicap to weavers on the reservation because of the limited supply of water and facilities for scouring wool. In addition, the short staple length of the Rambouillet wool is undesirable for the production of strong hand-spun yarns.

In this test it was found that the length and proportion of fine and coarse fibers best adapted to hand weaving were associated with Navajo wool of medium fineness, equal in mean diameter to U. S. grades 50's and 56's. It was not possible, however, to determine from this test whether the average diameter of the wool or the diameter dis-

323434°—41——3

tribution of the fibers was of greater importance from the standpoint of its suitability for rug weaving.

In the second experiment the effect, on rug texture, of variations in fiber-diameter dispersion (table 4) was determined. Variations in length of staple are shown in table 5. All five lots of wool used had practically the same mean fiber diameter, being equal to grade 56's. The differences in fiber-diameter distribution caused much variation

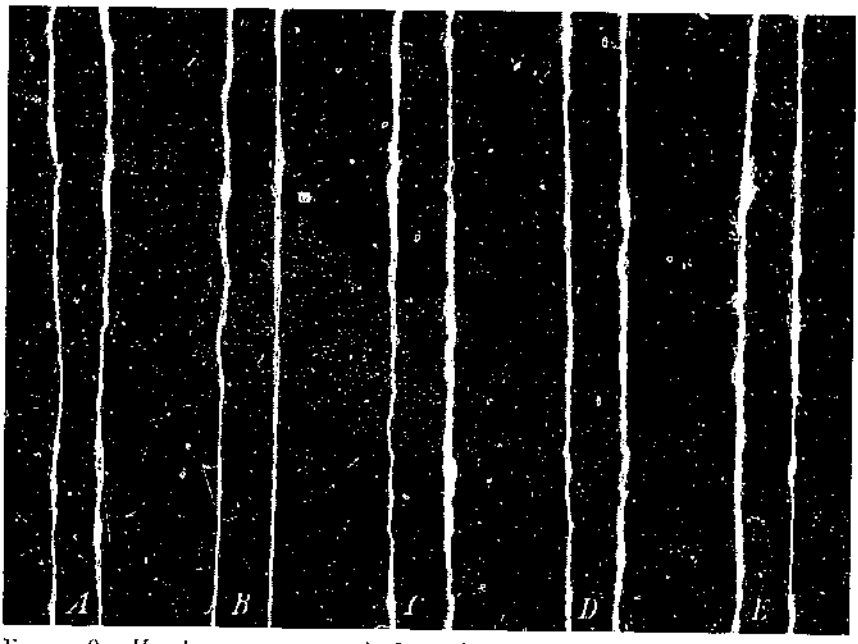


FIGURE 9.—Hand-spun yarns made from five lots of Navajo wool of medium fineness. The rougher yarns are associated with the greater quantities of kemp and coarse outercoat fibers in the wool; *A* to *E*, lots 1 to 5, respectively.

in the relative uniformity and smoothness of the hand-spun yarns, as shown in figure 9.

Lot 1 represented the best wool produced by the breeding flock from the standpoint of uniformity in fiber diameter and freedom from kemp. The yarn spun from this wool was extraordinarily smooth and uniform in diameter and produced a rug of superior texture to those made from other lots of wool used in this test.

The rug made from wool of lot 2 was not so uniform and smooth because of the higher proportion of very fine and very coarse fibers. After a few months of wear, these small differences in texture probably would not be apparent.

TABLE 4.—*Variations in fiber-diameter dispersion in five lots of medium-fine Navajo wool produced by experimental sheep (experiment 2)*

Lot No.	Fiber diameter[1]	Standard deviation[1]	Fibers with diameters of—					Medullated fibers[2]			
			11μ–20μ	21μ–30μ	31μ–40μ	41μ–50μ	More than 50μ	Kemp	Large	Medium	Small
	Microns	*Microns*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	28.7	7.8	14.6	51.0	26.0	8.0	0.4	0.4	0.0	0.2	0.4
2	27.8	9.3	26.2	42.6	18.0	12.4	1.4	0.0	0.0	.2	1.6
3	27.6	10.9	29.6	45.9	9.6	11.6	4.8	1.0	.6	1.0	6.6
4	28.8	12.6	40.6	31.0	3.8	17.2	8.0	3.2	.4	.6	5.6
5	28.6	15.7	32.4	45.4	4.9	5.9	11.4	2.6	1.2	2.4	6.2

[1] Kemp and medullated fibers included.
[2] See footnote 2, table 1.

TABLE 5.—*Length and proportion of outercoat and undercoat fibers in five lots of medium-fine Navajo wool produced by the experimental sheep (experiment 2)*

Lot No.	Outercoat fibers		Undercoat fibers	
	Length	Proportion by weight	Length	Proportion by weight
	Centimeters	*Percent*	*Centimeters*	*Percent*
1	21.0	25.2	12.4	74.8
2	22.2	44.5	11.1	55.5
3	24.1	39.0	15.4	61.0
4	21.6	45.9	10.5	54.1
5	18.4	31.4	9.8	68.6

A greater degree of coarseness and harshness of texture was associated with the rug woven from wool of lot 3, owing to the higher percentage of kemp and outercoat fibers. The quantities of these fibers were not sufficient to constitute a serious objection; nevertheless, the rug was of less desirable quality than those woven from lots 1 and 2.

Lots 4 and 5 produced rugs with an extremely coarse and harsh texture. This effect was somewhat more pronounced in the latter rug. The excessive quantity of kemp affected the spinning and dyeing properties of the wool. The straightness and coarseness of the kemp fibers facilitated carding to some extent, but their short length and greater size prevented the normal floating of the fibers during the spinning process. The yarns were bristly in appearance, somewhat uneven in diameter, and after dyeing were dull and lacked uniform coloring. These characteristics detracted greatly from the appearance and value of the rugs.

The wide variations in shrinkage of the five lots of wool used in this experiment (table 3) were largely due to the foreign material in the wool. The quantity of natural yolk was not sufficient in any instance to make the wool greasy as is generally true of fine wools. Environmental conditions in this semidesert country normally cause much variation in the shrinkage of Navajo wool.

Navajo wool containing an excessive proportion of long and very coarse outercoat fibers and a high frequency of kemp is illustrated in figure 10. This wool had a mean fiber diameter of 37.6μ, with a

range of 18μ to 117μ. The standard deviation of the diameter measurements was 16.0μ. There were 23 percent of fibers more than 40μ in diameter, with slightly more than half of these exceeding 50μ.

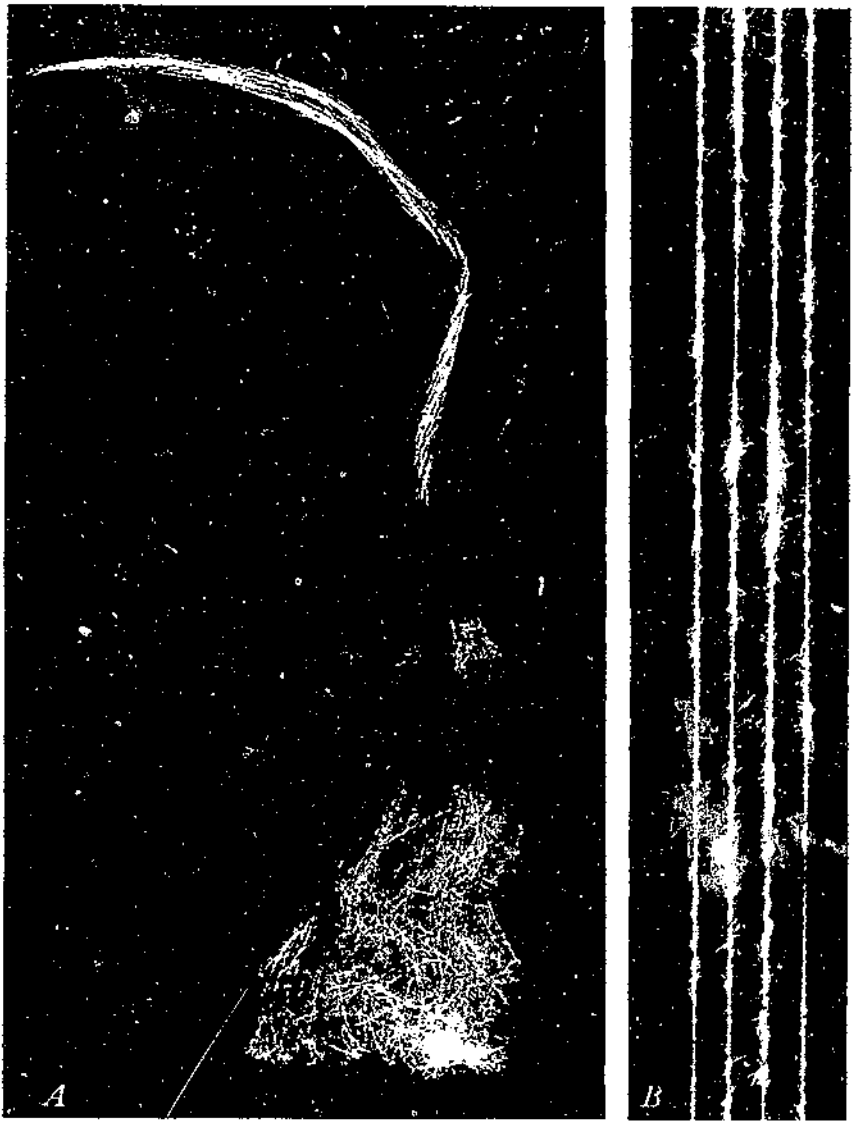


FIGURE 10. *A*, Lock of Navajo wool showing undesirable characteristics. Outercoat fibers are extremely long and coarse, and the wool contains an excessive quantity of kemp. *B*, Hand-spun yarns from *A*, showing coarse, opaque kemp fibers protruding from the yarns. Kemp seriously affects the spinning properties of the wool.

The extreme coarseness and high proportion of the outercoat fibers and a frequency of 3.3 percent of kemp were responsible for the coarse, harsh texture of the resulting yarns and rug, which are also shown in figures 10 and 11.

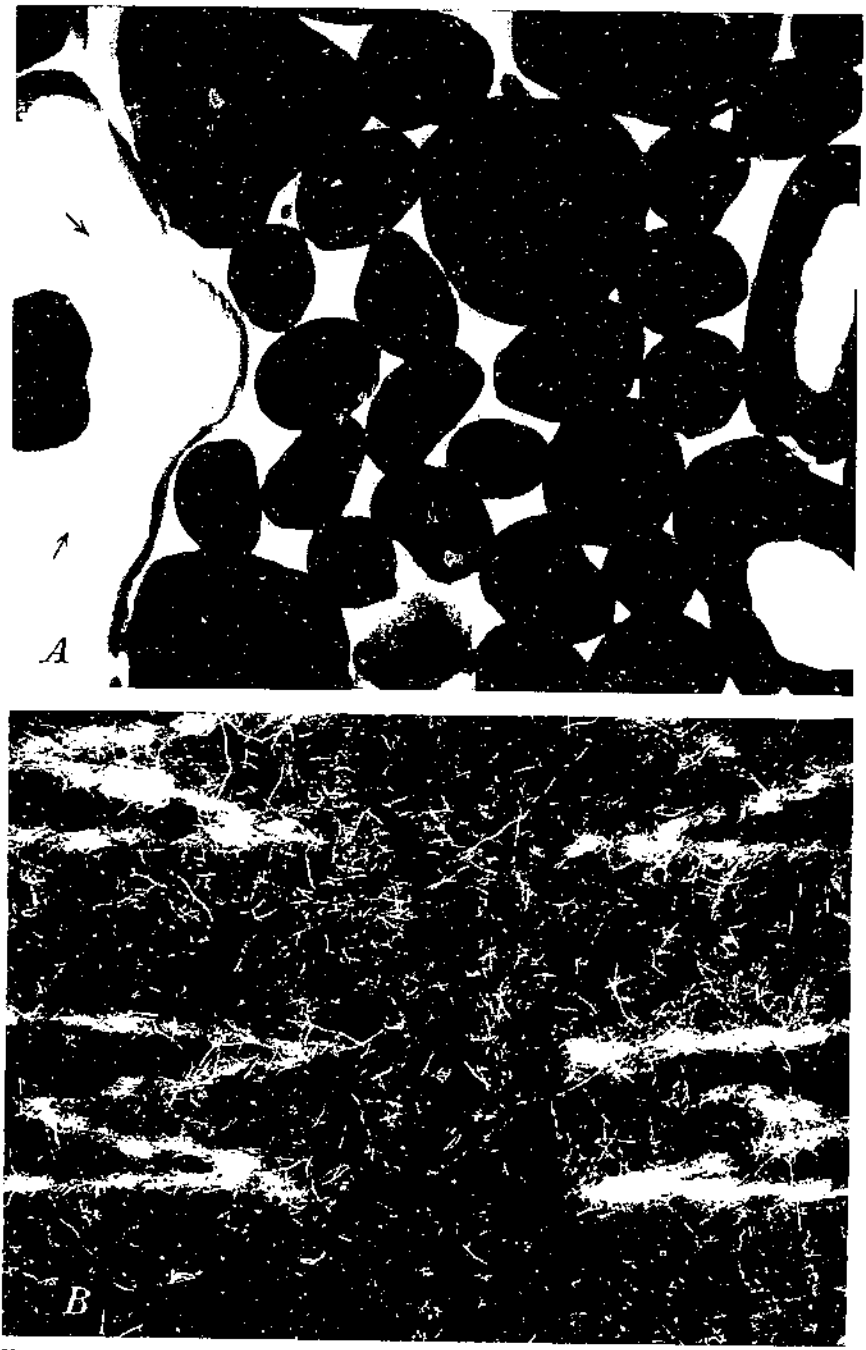


FIGURE 11.—*A*, Cross sections of wool fibers shown in figure 10. × 500. Note the great range in size of the fibers and the very large medulla of the kemp fiber at extreme left. *B*, Hand-woven rug from this wool, showing extremely coarse and harsh texture. Note that the kemp fibers appearing on the surface are not evenly dyed.

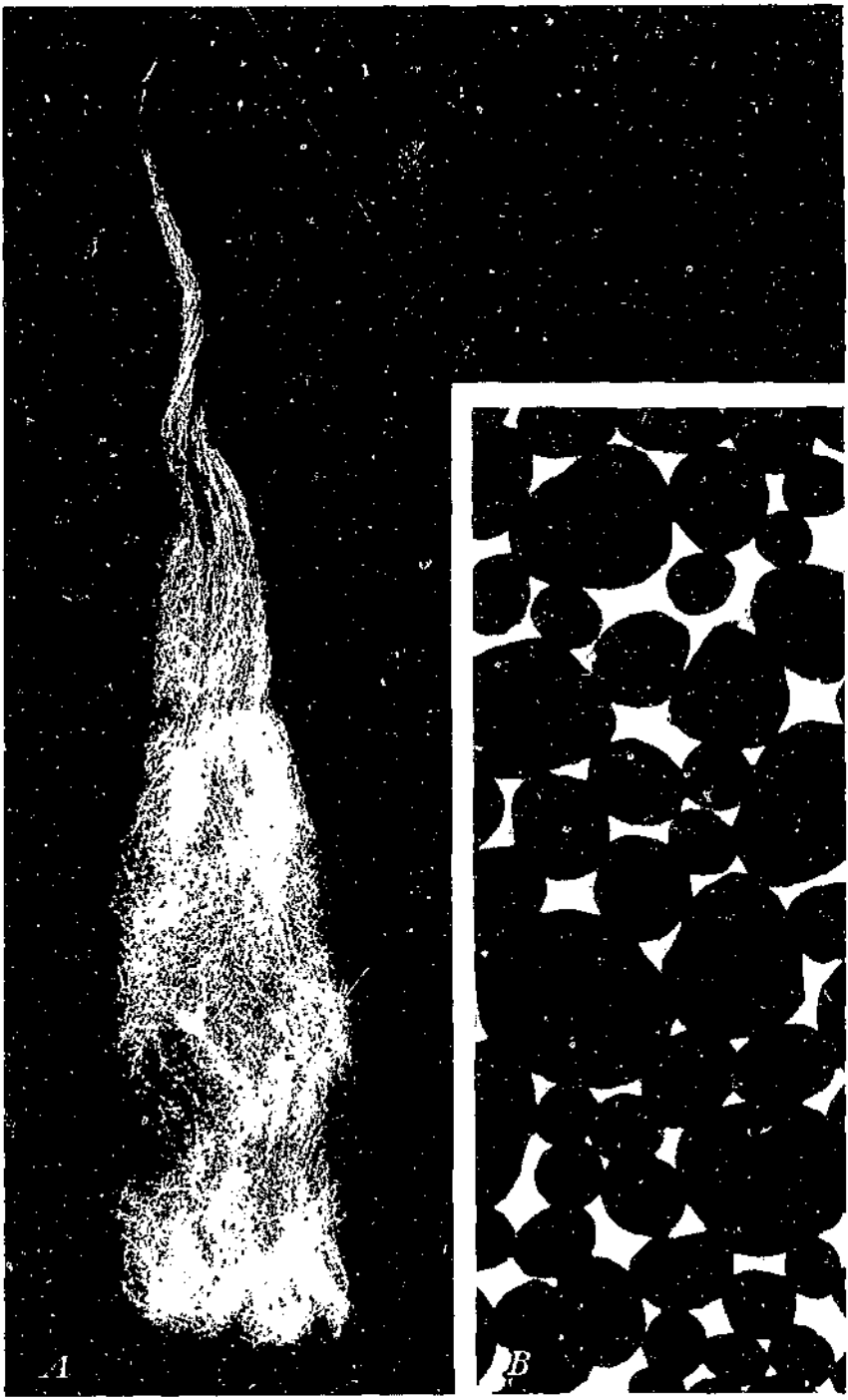


FIGURE 12.—*A*, Lock of Navajo wool well adapted for hand weaving; *B*, cross sections of wool fibers (× 500) showing low proportion of coarse fibers and absence of kemp and other medullated fibers.

In the third experiment, the influence of variations in fiber-diameter distribution was determined for Navajo wool corresponding in fineness to grades 50's and low 60's. Results of these tests substantiated those made with Navajo wool of medium fineness. In each instance the most uniform wool produced the greatest uniformity in diameter and smoothness of yarn and the highest quality of texture in the rug. The diameter dispersion for coarse, medium, and fine Navajo wool of high uniformity differed materially in the proportion of extremely fine fibers but only slightly in the proportion of coarse and extremely coarse fibers. Fibers between 10μ and 20μ in diameter ranged from approximately 35 percent for grade 60's to 9 percent for grade 50's. On the other hand, fibers between 40μ and 50μ in diameter varied from about 7 to 11 percent. In each instance fewer than 1 percent of fibers were more than 50μ in diameter.

The data in tables 1 and 4 illustrate a fundamental fact regarding Navajo wool, namely, that no constant relationship exists between fineness of the wool and fiber-diameter dispersion. Variations in the percentage and size of the undercoat, outercoat, and kemp fibers were responsible for the differences in fiber-diameter distribution of the various lots of wool used in both the first and second experiments. The results of these weaving tests demonstrated definitely that rug quality was influenced most by the proportion and diameter distribution of the coarse outercoat and kemp fibers. A low proportion of fibers more than 40μ in diameter with no kemp was found to be most satisfactory.

The Navajo wool shown in figures 12 and 13 meets the requirements for good weaving wool, as demonstrated by the thoroughly carded wool, the uniform hand-spun yarns, and the smooth, even texture of the rug. This wool had a range in fiber diameters of 16μ to 56μ. Only 8 percent of the fibers were more than 40μ in diameter and 0.4 percent more than 50μ. The wool was free from kemp and other medullated fibers. It contained 25.4 percent, by weight, of outercoat fibers, with an average length of 17.3 cm. The average length of the undercoat fibers was 10.9 cm. Shrinkage of the fleece was 46 percent.

Old Navajo Blankets and Rugs

Fiber-diameter measurements of yarn samples from the 162 old specimens were analyzed to determine how blanket and rug quality was influenced by (1) the average fineness and fiber-diameter dispersion of the wool, (2) the percentages of coarse outercoat fibers and kemp fibers, and (3) the percentage and size of medullae in the fibers.

A study of the fiber-diameter distributions showed that the old blankets and rugs were woven from five different qualities of wool. Figure 14 gives the fiber distribution of a blanket or rug representing each of these five qualities. Although in the different wools there was a range in average fineness of approximately 12μ, their fundamental differences were in dispersion and percentage of fibers more than 40μ in diameter. No single wool quality was confined solely to the blankets and rugs of any one of the four periods.

Figure 14, *a*, shows the fiber distribution of a sample containing no outercoat fibers. The wool in this sample was fully as uniform as an improved wool of Half Blood fineness. Average diameter of the fibers was 25.2μ, with a standard deviation of 4.6μ. The curve closely

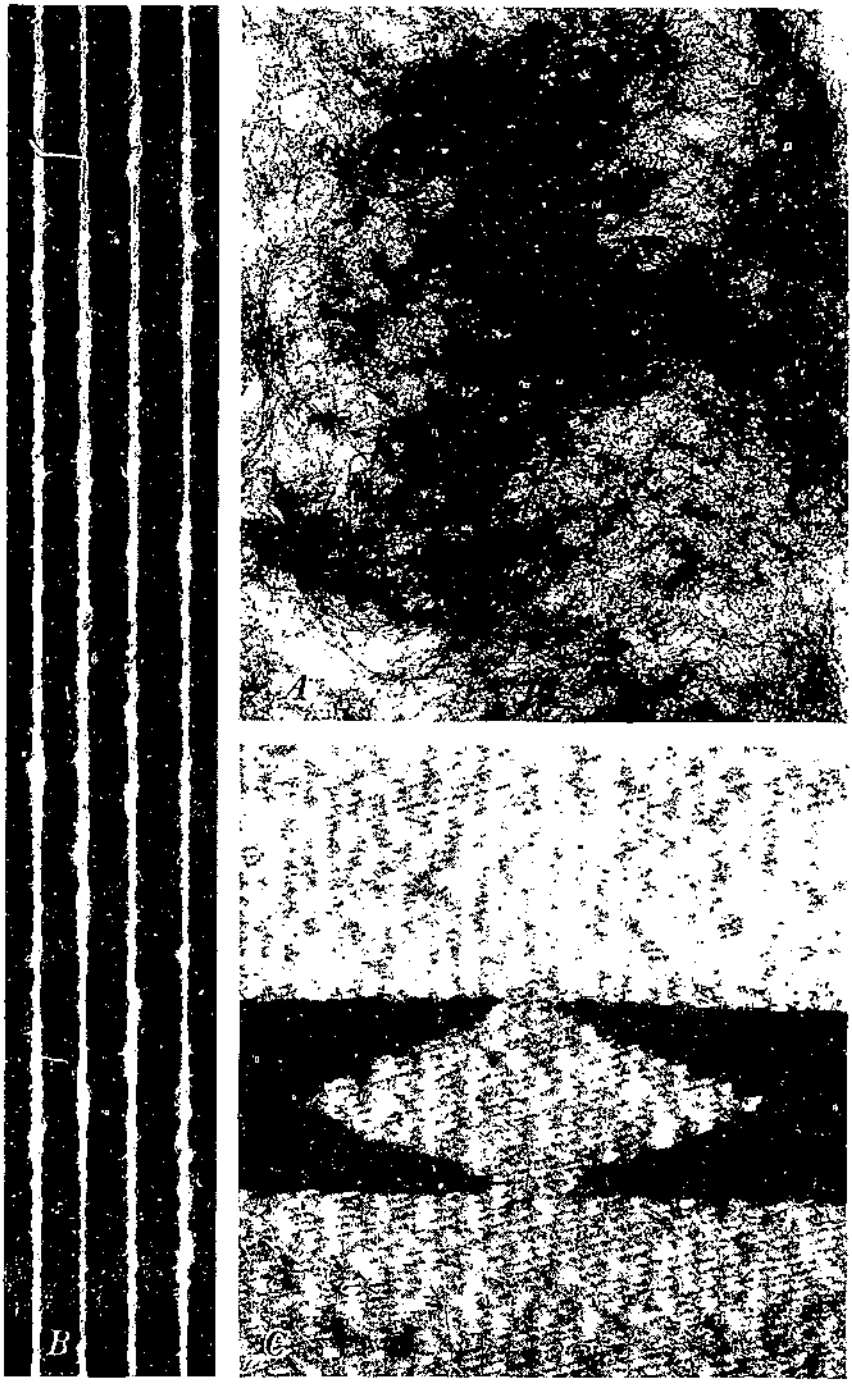


FIGURE 13.—*A*, Hand-carded wool, with well-separated fibers; *B*, hand-spun yarns, showing desirable uniformity; *C*, hand-woven rug from this wool, the smooth texture of which is in marked contrast to that shown in figure 2.

approximates a normal distribution, whereas the distributions typical of Navajo wool, containing both the undercoat fibers and the outercoat and kemp fibers, are positively skewed and occasionally bimodal. Only 4 percent of the old specimens were woven from *quality a* wool. The texture of one of these, a fine shoulder blanket of the third period, is shown in figure 15. The general characteristics of the blanket indicated that it was woven before the introduction of improved breeds of sheep on the reservation. In view of this fact it seems probable that the blanket was made from the undercoat of Navajo fleeces, from which the outercoat fibers had been hand-separated. This practice was sometimes followed by Navajo weavers. Although similar in fineness to Rambouillet wool, the undercoat fibers have

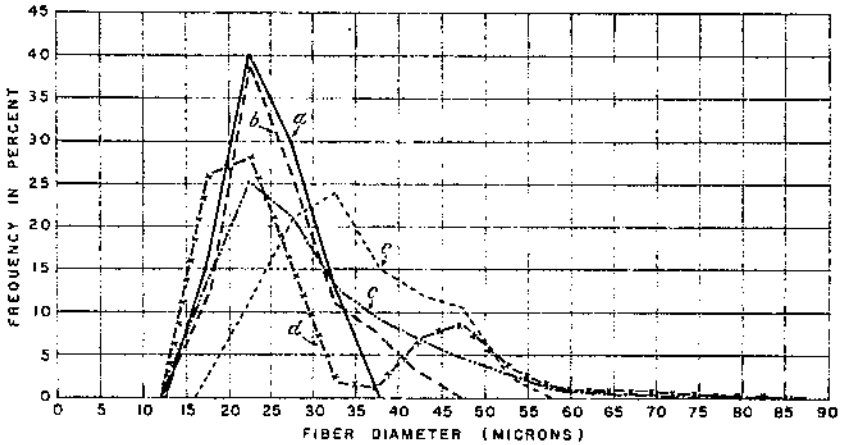


FIGURE 14.—Fiber-diameter distribution of five Navajo blankets and rugs made from five different qualities of wool: *a*, Fine old Navajo shoulder blanket of the third period, containing no outercoat fibers; *b*, fine Classic blanket of the second period, containing a low percentage of outercoat fibers; *c*, coarse rug of the third period, containing a medium percentage of outercoat and kemp fibers; *d*, coarse rug of the fourth period, containing a high percentage of outercoat and kemp fibers; *e*, fine Chief blanket of the second period, woven from a uniformly coarse wool.

considerably less crimp, as previously shown, and therefore could be carded and spun into a fine, smooth yarn.

Approximately 67 percent of the old blankets and rugs were woven from Navajo wool containing a low percentage of outercoat fibers. A high proportion of these specimens were found in the second and third periods of weaving and were of the highest quality. Figure 14, *b*, shows the diameter distribution of one of the most uniform samples, containing 3.3 percent of outercoat fibers more than 40μ in diameter. This sample averaged 26.5μ in diameter, with a standard deviation of 6.2μ, and contained less than 1 percent of kemp and other medullated fibers. The smooth, even texture of the Classic blanket in plate 1 and the rug in plate 2, made from this quality of wool, is shown in figures 16 and 17.

The skewed distribution illustrated by figure 14, *c*, represents that of a sample containing a medium percentage of outercoat fibers with a wide range in diameter. There were 11.5 percent of coarse fibers and 5.5 percent of extremely coarse fibers averaging 44.9μ and 58.7μ

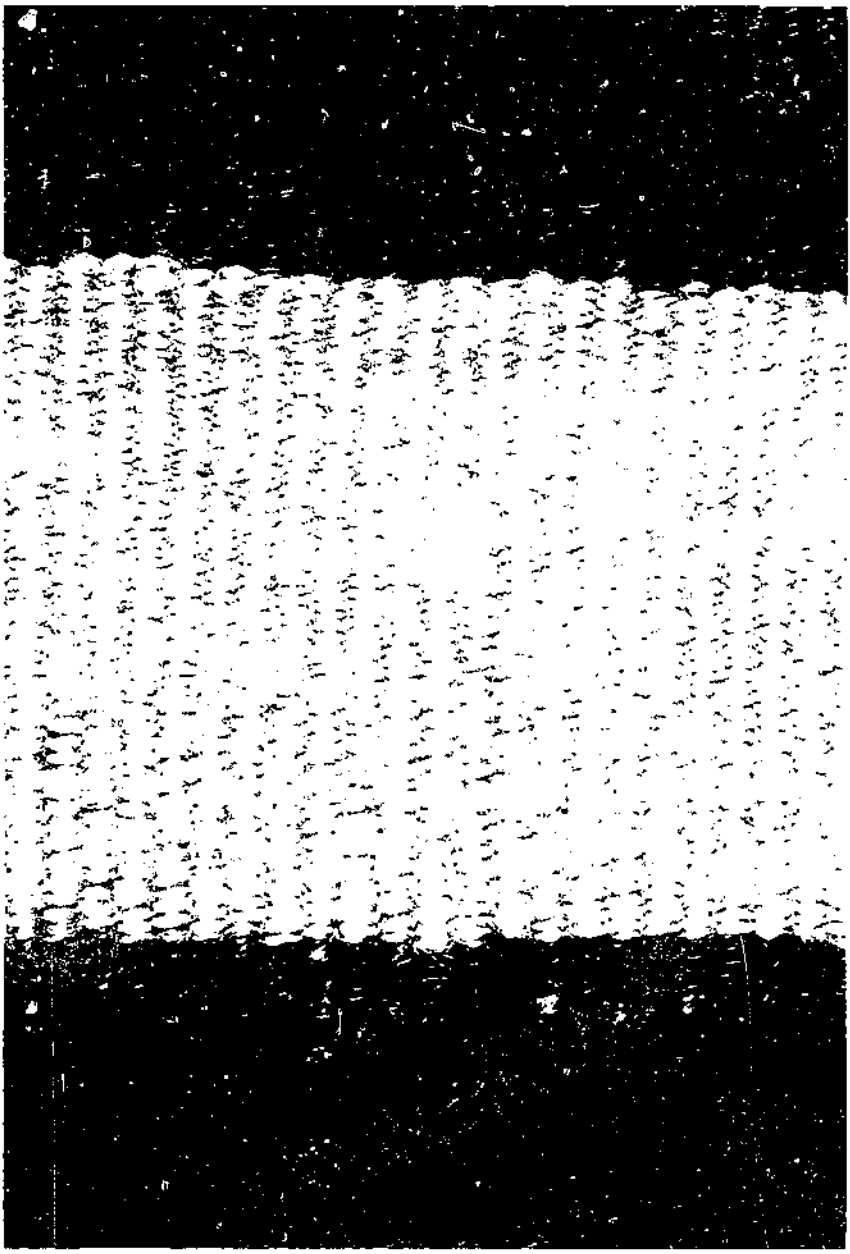


Figure 15.—Old Navajo shoulder blanket of fine texture, woven from extremely uniform wool containing no coarse outercoat or kemp fibers. × 2. Yarn count, 12 warp and 72 weft per inch.

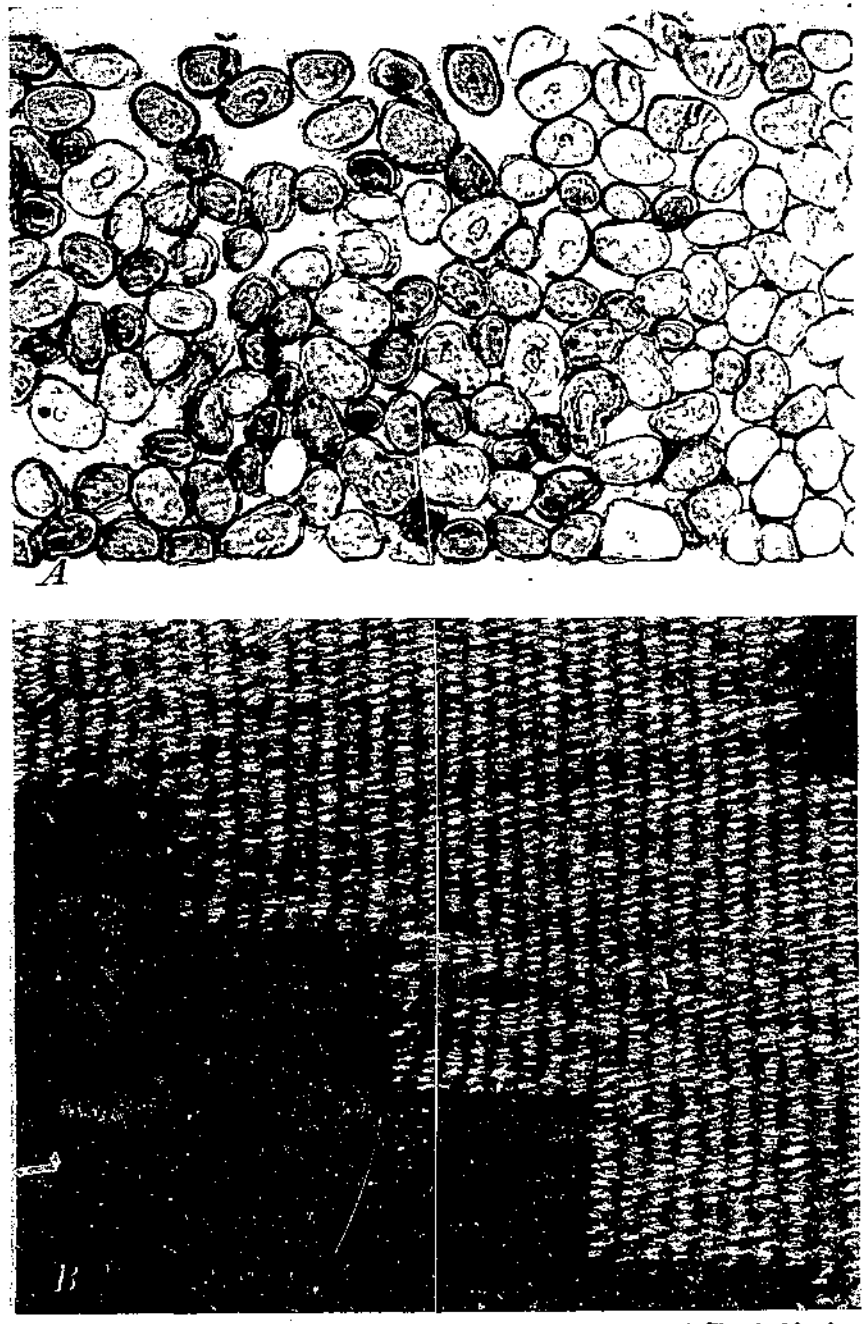


FIGURE 16.—*A*, Cross sections of wool fibers from weft yarns of Classic blanket illustrated in plate 1. × 250. This wool is of medium fineness and has a high degree of uniformity in diameter. The outercoat fibers show some medullation. *B*, The fine, smooth, even texture of the blanket is proof that the wool was especially adapted for Navajo weaving. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)

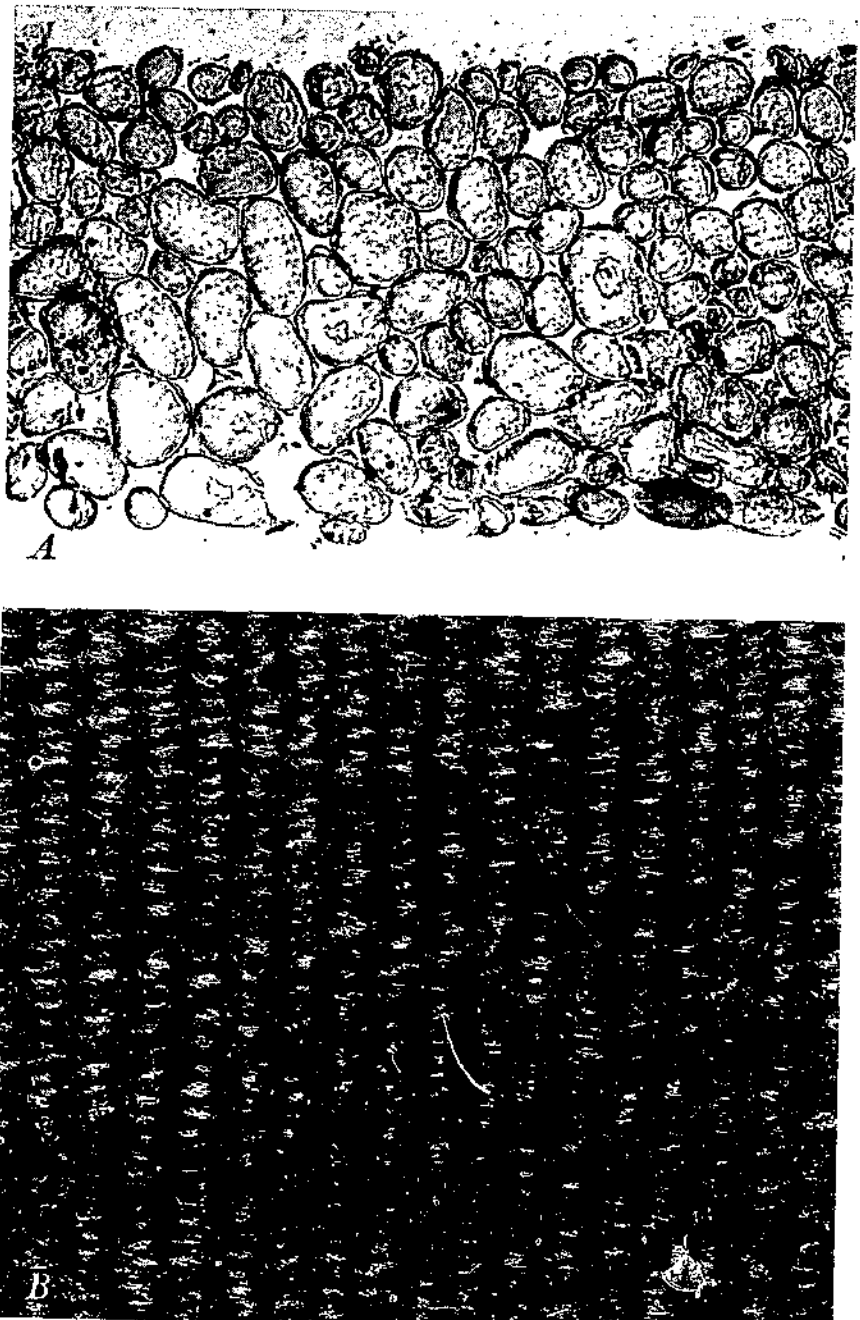


FIGURE 17.—*A*, Cross sections of wool fibers from weft yarns of rug illustrated in plate 2. × 250. The Navajo wool was somewhat less uniform in diameter than that used in the Classic blanket, plate 1. *B*, The smooth texture of the rug is similar to that of the Classic blanket except in fineness of yarns. (Courtesy of Laboratory of Anthropology, Santa Fe, N. Mex.)

in diameter, respectively. Included in these fiber groups were 1.8 percent of kemp fibers and 8.7 percent of medullated outercoat fibers. Of all the specimens studied, approximately 23 percent were woven from wool of this quality. With one exception, they were classified in the first, third, and fourth periods. These specimens were generally of coarser texture and less desirable quality (fig. 18) than those woven from Navajo wool containing a low percentage of outercoat fibers.

In some of the coarser yarn samples there was a more distinct segregation of undercoat and outercoat fibers, resulting in a bimodal distribution similar to that shown by figure 14, *d*. This sample contained 15.6 percent of coarse fibers and 7.1 percent of extremely coarse fibers, which averaged 45.8μ and 58.0μ in diameter, respectively. There were 4.5 percent of kemp and 8.1 percent of other medullated fibers in the sample. However, after nearly 45 years of continuous service the rug was worn smooth, and the effects of a high proportion of outercoat and kemp fibers were not apparent to the naked eye, as is shown in figure 19.

Figure 14, *e*, shows the fiber distribution of a sample from one of the fine Chief blankets of the second period of weaving, yet the wool represents an entirely different type from that used in the other Chief blankets studied. The average diameter of the wool fibers was 37.7μ and the standard deviation 8.4μ, which correspond closely to those of certain coarse wools from improved breeds of sheep. Although this wool contained 23 percent of coarse fibers, it was distinctly superior to the typical coarse Navajo wool because of the uniformity in diameter of the fibers and the very low content of kemp and other medullated fibers. The blanket from which this sample was obtained was not distinguishable in quality from the fine Classic blanket, plate 1, despite the fact that the wool was much coarser.

The fiber-diameter distributions of all blanket and rug samples were analyzed on the basis of the five wool qualities shown in figure 14. A summary of these data is given in table 6. The mean diameters and standard errors of the wool fibers increased consistently from qualities *a* to *d*. Furthermore, the mean percentages of kemp fibers and of large, medium, and small medullae also increased in relation to the quantity of coarse fibers contained in the wool. Wool of quality *e*, for which there were only two samples, averaged somewhat coarser than that of quality *d* but it had a lower dispersion than either *c* or *d* and little kemp. In the wool samples of qualities *a* to *d*, there was a consistent decrease in the percentages of fine and extremely fine fibers (having diameters of 21μ–30μ and 11μ–20μ, respectively) and an increase in the percentages of coarse and extremely coarse fibers (having diameters of 41μ–50μ and more than 50μ, respectively). Wool of quality *e* followed the same general trend except for the lower percentage of fibers more than 50μ in diameter. Variations were largest in the percentages of fine and extremely fine fibers.

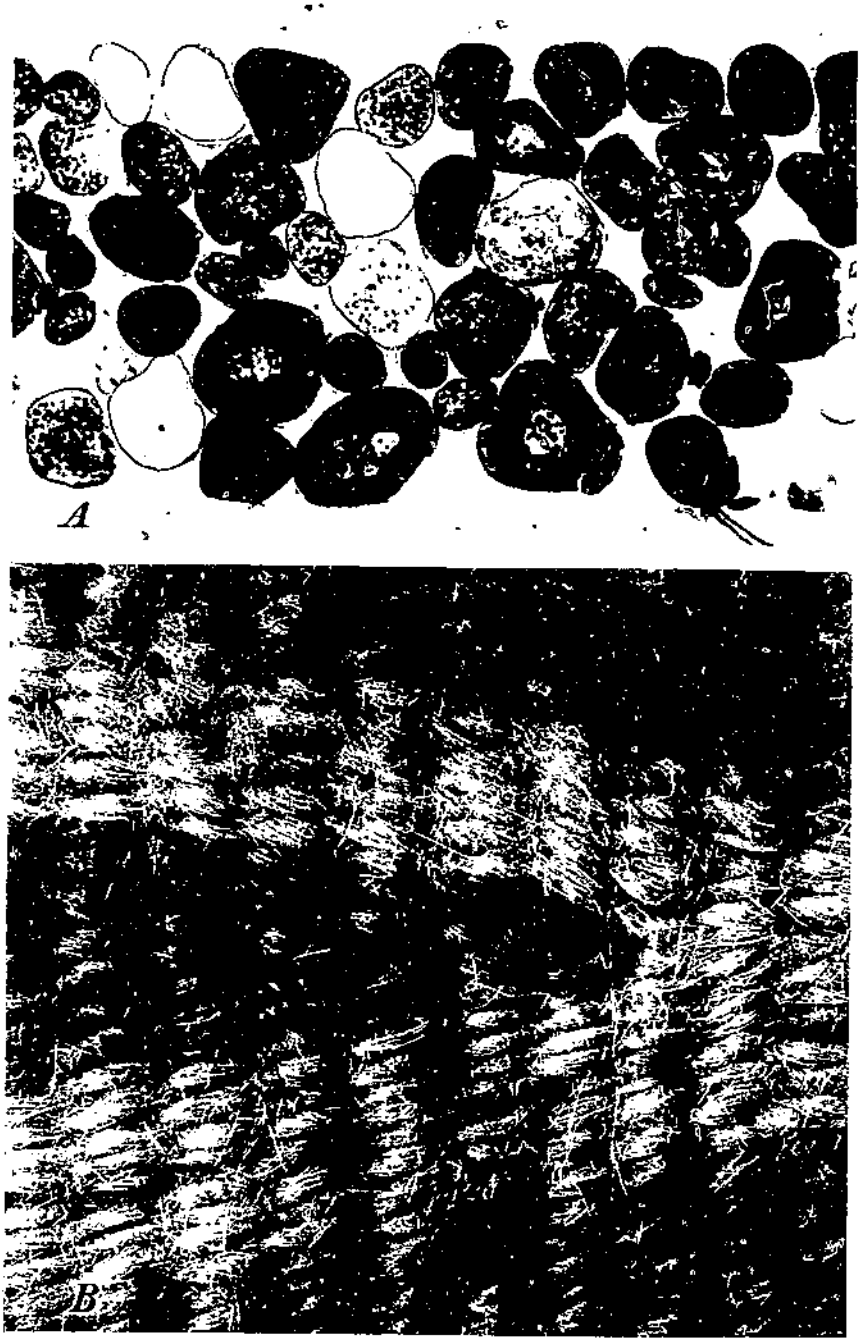


FIGURE 18.—*A*, Cross sections of fibers (× 250) from weft yarn of rug shown in *B*. Note the high proportion of coarse, medullated fibers compared with that shown in figure 16. *B*, Coarse texture of an inferior Navajo rug of the third period. × 2. Yarn count, 5 warp and 23 weft per inch.

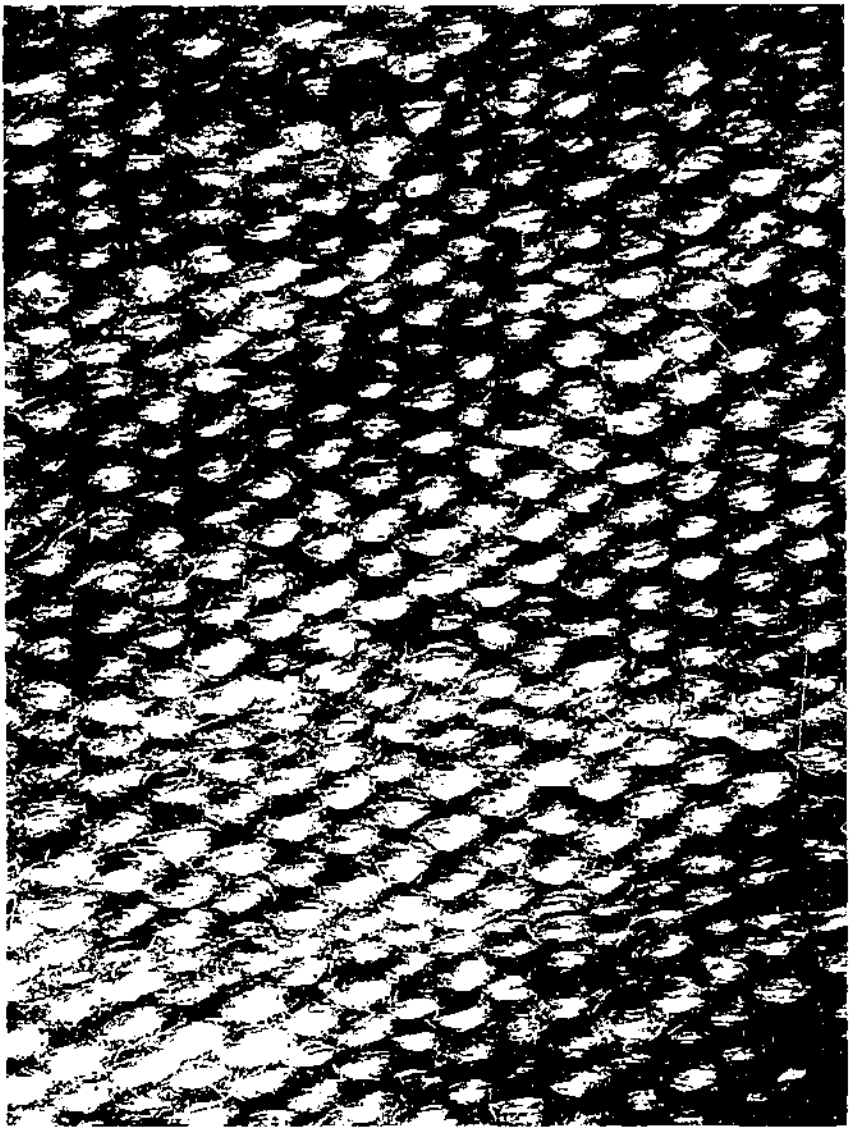


FIGURE 19.—Navajo rug after nearly 15 years of continuous service. It was woven from the least desirable quality of Navajo wool containing a high percentage of coarse outercoat and kemp fibers. Yarn count, 7 warp and 18 weft per inch.

TABLE 6.—*Mean fiber diameters, standard errors, and percentages of kemp and other medullated fibers in the wool of old Navajo blankets and rugs, classified according to wool quality*

Wool quality[1]	Samples in weaving period No.—					Fiber diameter[2]	Fibers with diameters of—					Medullated fibers[3]			
	1	2	3	4	Total		11μ–20μ	21μ–30μ	31μ–40μ	41μ–50μ	More than 50μ	Kemp	Large	Medium	Small
	No.	*No.*	*No.*	*No.*	*No.*	*Microns*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
a	0	1	5	1	7	23.5±0.04	28.4	64.5	7.1	0.0	0.0	0.06	0.02	0.02	0.46
b	2	37	57	13	109	26.9± .23	18.3	56.1	20.8	4.0	.8	.58	.29	.51	1.49
c	5	1	21	11	38	30.0± .32	18.3	48.0	19.6	10.0	4.1	1.18	.51	.89	2.18
d	1	0	2	3	6	33.2±1.68	11.9	42.1	20.1	15.1	10.8	2.67	1.87	1.66	3.02
e	0	2	0	0	2	34.9±2.92	4.6	40.2	30.8	22.4	2.0	.21	.67	2.25	4.81

[1] For a description of the wool qualities, see figure 14.
[2] Kemp and medullated fibers included.
[3] See footnote 2, table 1.

The data for all blanket and rug samples were also analyzed by periods of weaving, as shown in tables 7 to 9, inclusive. The period means represent an average of the individual samples within the respective periods of weaving.

Blanket fragments of the first period were coarser than those of later periods, but for the most part the wool contained fewer kemp and other medullated fibers. The mean fiber-diameter of 30.1±0.69μ was associated with the lowest percentages of fine and extremely fine fibers and the highest percentages of coarse and extremely coarse fibers.

The choice Classic and Chief blankets of the second period were intermediate in fiber diameter and lowest in percentages of coarse and extremely coarse fibers. The fiber characteristics for the period were similar to those of the quality *b* wool, which was the best quality used in the old blankets and rugs.

TABLE 7.—*Mean fiber diameters and standard errors of old Navajo blankets and rugs by chronological periods of weaving*[1]

Period of weaving		Specimens sampled	Dominating product studied	Fibers measured	Fiber diameter[2]
No.	Year				
		Number		*Number*	*Microns*
1	1800–1850	8	Blankets	9,296	30.1±0.69
2	1850–70	41	do	27,549	27.5± .43
3	1870–90	85	Rugs	55,345	27.2± .25
4	1890–1915	28	do	20,396	28.0± .67
Total or mean		162		112,586	27.6± .08

[1] See footnote 1 of table 1.
[2] Standard error calculated on the basis of the specimens sampled and not the individual fibers.

TABLE 8.—*Mean percentages of fibers, including kemp and other medullated fibers, and their standard deviations in blankets and rugs of the four periods of weaving*

Period of weaving	Percentage of fibers with diameters of—									
	11μ–20μ		21μ–30μ		31μ–40μ		41μ–50μ		More than 50μ	
	Fibers	Standard deviation	Fibers	Standard deviation	Fibers	Standard deviation	Fibers	Standard deviation	Fibers	Standard deviation
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	12.4	5.7	50.0	6.0	22.1	9.1	11.5	2.8	4.0	3.7
2	14.8	11.4	57.0	8.1	23.4	9.9	4.2	4.7	.6	.8
3	19.1	10.4	54.6	9.7	18.9	7.8	5.6	4.1	1.8	2.0
4	22.9	12.4	47.9	11.4	17.9	9.6	7.4	4.9	3.9	4.9
Mean	18.4	11.2	53.9	9.9	20.0	8.9	5.9	4.6	1.9	2.8

Period of weaving	Medullated fibers[1]							
	Kemp		Large		Medium		Small	
	Fibers	Standard deviation	Fibers	Standard deviation	Fibers	Standard deviation	Fibers	Standard deviation
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	0.31	0.23	0.13	0.17	0.43	0.49	0.99	1.21
2	.30	.41	.16	.35	.20	.74	1.12	1.84
3	.74	.81	.37	.55	.71	.87	1.54	1.49
4	1.60	1.13	.89	1.07	1.00	.95	2.72	2.07
Mean	.77	.97	.39	.49	.64	.87	1.61	1.92

[1] See footnote 2 of table 1.

TABLE 9.—*Differences and significance of differences[1] between old blankets and rugs in indicated periods of weaving with respect to mean fiber diameters, and percentage of fibers coarser than 40μ*

Periods of weaving	Fiber diameters		Fibers coarser than 40μ in diameter	
	Difference	*t*	Difference	*t*
	Microns		*Percent*	
1 and 2	2.61	3.22**	10.75	5.21**
1 and 3	2.97	4.05**	8.15	4.09**
1 and 4	2.17	2.25*	4.25	2.05*
2 and 3	.36	.72	2.60	2.57*
2 and 4	.44	.55	6.50	5.05**
3 and 4	.80	1.11	3.90	3.82**

[1] **Highly significant; *significant.

In the third period there was a predominance of high-quality blankets and rugs and some of medium to coarse quality. Collectively, they were similar in mean diameter to the blankets of the second period but contained approximately twice the quantity of kemp and other medullated fibers. There were also a greater segregation in size of the undercoat and outercoat fibers and higher percentages of coarse and extremely coarse fibers.

The quality of the rugs in the fourth period was considerably more variable than that of the specimens of the second and third periods, and there was also a larger proportion of rugs with a coarse or medium coarse texture. Lower rug quality was associated with less desirable

wool in the fourth period. Mean fiber diameter for the fourth period was $28.0 \pm 0.67\mu$ compared to $27.5 \pm 0.43\mu$ and $27.2 \pm 0.25\mu$ for the second and third periods, respectively. Other factors which signified lower wool quality were: greater segregation of undercoat and outercoat fibers, higher percentages of coarse outercoat, kemp, and other medullated fibers.

The significance of the differences between the means of periods, as determined by the *t* test described by Fisher (*2*), is shown in table 9. The differences between the first period and the second and third periods in fiber diameter and percentages of fibers coarser than 40μ are highly significant. For the first and fourth periods the differences are significant. Between the second and third periods, the second and fourth periods, and the third and fourth periods, there are no significant differences in mean diameters, significant or highly significant differences in percentage of fibers coarser than 40μ.

It is apparent from these comparisons that the mean fiber diameter is a worthwhile criterion for evaluating Navajo wool only when considered in relation to the percentage of coarse fibers. The percentages of outercoat fibers and kemp fibers were dominant factors influencing texture and quality of these old blankets and rugs, but so far as could be observed the amount of medullation in the outercoat was not sufficient to affect the quality of the product.

The differences in wool quality between the specimens of various periods are undoubtedly due in part to the following factors: (1) Fundamental differences in the source and type of the specimens studied, (2) changes in the quality of Navajo wool resulting from different methods of sheep breeding and management and from different environment, (3) care exercised in the selection of the wool used for weaving, and (4) the amount of wear to which the blankets and rugs from which the samples had been obtained were subjected. As already stated, the old blanket fragments of the first period were recovered from caves and burials, a fact which indicates that they were more or less typical of the quality of blankets worn at that time by the Navajo people. Although these specimens were few in number, the data for them indicate that Navajo wool then contained a considerable quantity of outercoat fibers with less medullation than in the later periods of weaving. The low percentage of kemp may not be representative, however, since these fibers are extremely brittle and it is likely that some of them were lost through natural wear. The blankets and rugs of the second and third periods represent selected specimens of those woven between 1850 and 1890. The fact that a high proportion of these specimens were woven from the best quality of wool is no mere coincidence. Superior blankets and rugs were made by the most skilled weavers, who would naturally use the greatest care in the selection of their wool. Inferior rugs, on the other hand, resulted from a combination of less desirable wool and poorer workmanship. The rugs of the fourth period were probably more representative samples since many of them were still in actual use in private homes. These rugs were the most variable in quality, workmanship, and fiber characteristics but showed much similarity in these respects to the fragments of the first period.

Table 8 indicates that there has been a gradual deterioration in the quality of Navajo wool. As already indicated, this has resulted partly from poor methods of sheep breeding and management. Until

the intervention of the Federal Government no effort was made to improve Navajo sheep or wool.

Commercialization of Navajo weaving after 1880 was another factor that influenced the quality of the blankets and rugs. The change from weaving for tribal use to the production of blankets and rugs for monetary return resulted in a rapid expansion of the craft and an apparent carelessness in the selection, preparation, and weaving of the wool.

Despite the influence of these various factors, the old blankets and rugs studied, considered as a group, were distinctly superior to those woven in recent years from a fine, crimpy, short-stapled type of wool.

Comparison of Wool From Experimental Sheep With That in Old Blankets and Rugs

On the basis of the 5 wool qualities used in the weaving of the old blankets and rugs, the 4 lots of Navajo wool used in the first weaving experiment may be classified as follows: Lot 1 as quality *d*, containing a high percentage of outercoat and kemp fibers; lots 2, 3, and 4 as quality *c*, containing a medium percentage of such fibers. Lot 2, however, was close to the border line between qualities *c* and *d*. Similarily, the 5 lots of Navajo wool used in the second experiment may be classified as follows: Lot 1 as quality *b*, containing a low percentage of outercoat fibers; lots 2 and 3 as *c*; lots 4 and 5 as *d*. Owing to a high percentage and dispersion in diameter of the extremely coarse fibers of lot 5, it was classified in *d* but it was near the border line between *c* and *d*. Thus, only 1 of the 9 lots of experimental wool was equal to quality *b*, containing a low percentage of outercoat fibers, whereas 109 of the 162 old blankets and rugs studied were woven from this superior quality of wool. Of the 9 lots of wool woven at the laboratory, 5 were of quality *c*, containing a medium percentage of outercoat fibers, and 1 of these ranked low in desirability. Of the old specimens, 38 were made from the quality *c* wool. Quality *d* wool, containing a high percentage of outercoat fibers, was used in 6 of the old specimens and in 2 experimental rugs.

The means of the fiber diameters and their standard deviations for the various qualities of wool were as follows: Quality *b*, 28.7μ and 7.8μ, respectively, for the rugs woven at the laboratory and 26.9μ and 6.9μ for the old specimens; quality *c*, 28.9μ and 10.9μ for the former rugs and 29.0μ and 9.8μ for the latter; and quality *d*, 32.1μ and 13.0μ for the experimental rugs and 33.2μ and 12.2μ for the old specimens.

These data show that each of these three quality groups of wool that were used for experimental weaving was similar in average fineness to the wool in the old blankets and rugs but was consistently higher in dispersion. The diameter distributions of the wool used in the experimental rugs showed a general tendency toward greater segregation in size of the undercoat and outercoat fibers, resulting in higher mean percentages of the extremely fine, coarse, and extremely coarse fibers than in the old samples. Differences in the mean percentages of kemp and other medullated fibers were small.

In general, the relationship between wool type and the quality of the finished product was the same for the old blankets and rugs as for the ones woven at the laboratory. The quality of the old speci-

mens was also influenced by differences in workmanship and wear. The latter factor had a particularly important effect on texture. The coarse nap resulting from an excess of outercoat fibers and the harshness due to kemp, as demonstrated in the experimental weaving tests, had been largely eliminated from the old blankets and rugs as a result of natural wear and washing or dry cleaning. Nevertheless, the blankets and rugs made from wool containing a medium or high percentage of outercoat fibers and kemp were of less desirable texture than those made from a better quality of wool.

SUMMARY

The quality of Navajo blankets and rugs had been observed to be steadily deteriorating since about 1915, owing to the rapidly diminishing supply of the native Navajo wool, which is superior for handicraft purposes to the wool of sheep subsequently raised on the reservation. Therefore, a study was made by the United States Department of Agriculture, in cooperation with the Department of the Interior, at the Southwestern Range and Sheep Breeding Laboratory, Fort Wingate, N. Mex., from 1937 to 1939, to determine the physical characters of Navajo wool that make it particularly adapted to hand weaving by Navajo women.

As a part of this investigation, small experimental rugs were woven from selected lots of wool produced by the flock of Navajo sheep maintained at the laboratory. These sheep produced small fleeces of open, light-shrinking wool containing a mixture of short, fine undercoat fibers and long, coarse outercoat fibers and kemp fibers. The wool also has less crimp than most improved wools.

The wool used in the first weaving tests consisted of four lots of Navajo wool representing the approximate range in length and fineness of this wool and one lot of grade Rambouillet similar to that now used in many parts of the reservation. The variations in the quality of the rugs produced ranged from a somewhat lumpy texture in the rug woven from the short-stapled fine wool to a coarse, hairy texture in that woven from the coarsest Navajo wool containing a high proportion of extremely long and very coarse outercoat fibers. The short staple, fine crimp, density, and greasiness of the Rambouillet wool were found to be objectionable factors. Navajo wool of medium fineness had the most desirable length and proportion of undercoat and outercoat fibers for satisfactory carding and spinning and produced the best texture in the rug.

The second test involved five lots of wool that represented the range in fiber-diameter dispersion for Navajo wool of medium fineness. Variations in the quality of the resulting rugs demonstrated that the proportion and diameter distribution of the outercoat and kemp fibers were more important factors than average fineness of the wool. This conclusion was verified by a third test with Navajo wool equal in mean diameter to grades 50's and low 60's. In each instance the most uniform wool, containing approximately 7 to 11 percent of fibers between 40μ and 50μ in diameter and fewer than 1 percent of fibers exceeding 50μ, produced rugs of the most desirable smoothness, softness, and uniformity of texture.

Kemp in quantities of 2 percent or more, particularly when combined with a coarse outercoat, caused the rug to be uneven in color and harsh in texture.

The openness of fleece and the low percentages of grease and crimp in the fibers in Navajo wool greatly facilitated its manufacture by hand methods.

A study was also made of the fiber-diameter distribution and percentages of kemp and other medullated fibers of 162 old Navajo blankets and rugs. These specimens were woven between 1800 and 1915 and had been preserved in museum and private collections. For purposes of comparison, they were first analyzed on the basis of wool quality and second in four chronological periods of weaving. Five qualities of wool were found, and these wools represented a range in fineness of approximately 12μ. However, their differences in dispersion and percentages of outercoat fibers were most important. In general, the mean diameters and standard deviations of the 5 wools increased with the percentages of outercoat and kemp fibers. Wool of quality *a*, found in only 7 specimens, was equal in fineness and uniformity to a Half Blood wool and contained only an occasional kemp or other medullated fiber. The fiber-diameter distributions of the wool of qualities *b*, *c*, and *d* were typical of Navajo wool containing a low, medium, and high percentage, respectively, of outercoat and kemp fibers. There were 109 specimens of wool of quality *b*, 38 of *c*, and 6 of *d*. Quality *e*, of which there were only 2 samples, also contained a high percentage of coarse fibers, few kemp, and was equal in diameter dispersion to that of an improved coarse wool.

Blanket fragments of the first period (1800–1850) were principally of quality *c* wool and of medium-coarse texture. Of the blankets in the second period (1850–70), 90 percent were woven from quality *b* wool and were of outstanding texture. The two blankets made from quality *e* wool were similar in texture to others of this period. Wool qualities *b* and *c* predominated in the third period (1870–90). A high proportion of the blankets and rugs were of excellent texture, but some containing a medium or high percentage of outercoat fibers and kemp were less desirable. One of the blankets made from quality *a* wool was of extremely fine texture. Rugs of the fourth period were most variable and of lowest average quality. Half of these rugs were made from wool of qualities *c* and *d*. Mean percentages of kemp fibers were highest in rugs of the fourth period.

Between the first and the second and third periods differences in fiber diameters and percentages of coarse fibers were highly significant. Between the second and the third and fourth periods and also between the third and the fourth periods, there was a significant or highly significant difference only for the percentages of coarse fibers.

Comparison of the fiber-diameter distributions of the experimental rugs and of the old blankets and rugs showed that within wool types, the mean diameters were relatively close, but the standard deviations were consistently higher for the rugs woven from wool produced by the experimental sheep. The same general relationship between wool and rug quality was found for both the old and new specimens. Differences in workmanship and wear also influenced the appearance of the old blankets and rugs. After many years of use, most of them were worn smooth, and the effects of variations in wool quality were not nearly so apparent as in the rugs woven from wool from the experimental sheep. By control of these factors in the weaving tests, the importance of suitable wool was established.

The results of these studies show that wool best adapted for the Navajo handicraft must have certain physical properties. These are as follows: An open type of fleece, with a low content of natural yolk; a low percentage of crimp in the fibers and a broad or irregular crimp as contrasted with the close, well-defined crimp of Rambouillet wool; a medium length of staple of between 10 cm. and 20 cm.; 5 to 10 percent of fibers more than 40μ in diameter, with the maximum uniformity obtainable in wool of this type; practical freedom from kemp and other medullated fibers.

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